US009131522B2

(12) **United States Patent**
Behnamfar et al.

(10) **Patent No.: US 9,131,522 B2**
(45) **Date of Patent: Sep. 8, 2015**

(54) **TIME-FREQUENCY SCHEDULING TO IMPROVE MULTI-RADIO COEXISTENCE**

(71) Applicant: **QUALCOMM Incorporated**, San Diego, CA (US)

(72) Inventors: **Firouz Behnamfar**, San Jose, CA (US); **Sandip HomChaudhuri**, San Jose, CA (US); **Paul Husted**, San Jose, CA (US); **Alireza Raissinia**, San Jose, CA (US); **Qinfang Sun**, San Jose, CA (US)

(73) Assignee: **QUALCOMM INCORPORATED**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 124 days.

(21) Appl. No.: **13/891,148**

(22) Filed: **May 9, 2013**

(65) **Prior Publication Data**

US 2014/0056276 A1 Feb. 27, 2014

Related U.S. Application Data

(60) Provisional application No. 61/692,152, filed on Aug. 22, 2012.

(51) **Int. Cl.**

H04W 4/00	(2009.01)
H04W 72/12	(2009.01)
H04W 16/14	(2009.01)
H04W 72/04	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 72/1257*** (2013.01); ***H04W 16/14*** (2013.01); ***H04W 72/1215*** (2013.01); *H04W 72/042* (2013.01); *H04W 72/1289* (2013.01)

(58) **Field of Classification Search**

USPC 370/329–331, 341–349, 401–465; 455/450–522

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,072,918	B2	12/2011	Muharemovic et al.
8,295,395	B2	10/2012	Mueck et al.
8,331,951	B2	12/2012	Zhang et al.
8,605,615	B2	12/2013	Frank et al.
8,665,810	B2	3/2014	Wu
8,737,924	B2	5/2014	Fu et al.
8,848,607	B2	9/2014	Wang et al.
2008/0205365	A1	8/2008	Russell et al.
2009/0111500	A1	4/2009	Sudak et al.
2010/0034126	A1	2/2010	Kitazoe et al.

(Continued)

FOREIGN PATENT DOCUMENTS

WO 2011123531 A1 10/2011

OTHER PUBLICATIONS

International Search Report and Written Opinion—PCT/US2013/054012—ISA/EPO—Feb. 6, 2014.

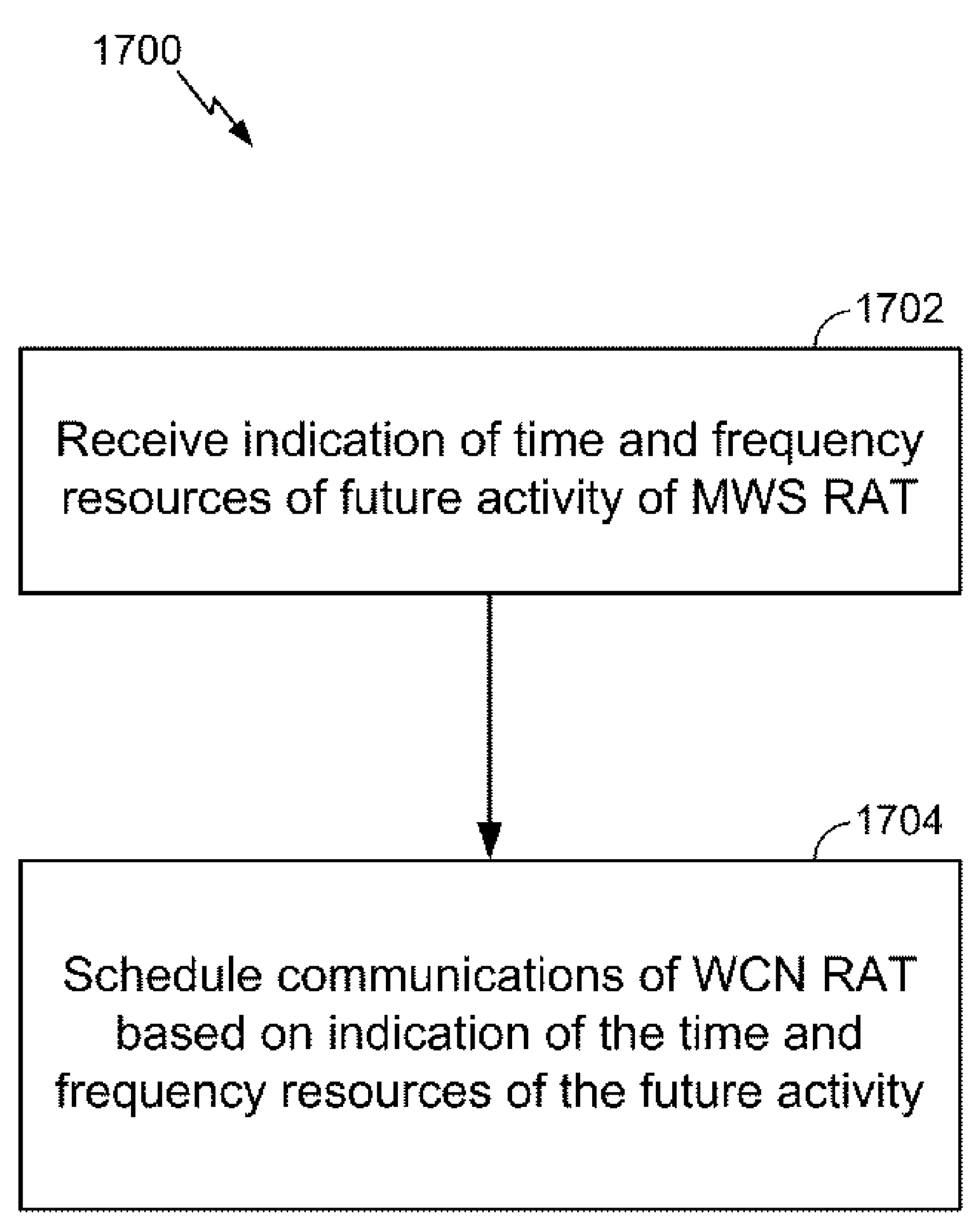
Primary Examiner — Man Phan

(74) *Attorney, Agent, or Firm* — Seyfarth Shaw LLP

(57) **ABSTRACT**

A user equipment (UE) uses information regarding dynamic resource allocation in a mobile wireless service (MWS) radio access technology (RAT) to improve MWS and wireless connectivity network (WCN) RAT coexistence. The UE may receive an indication of time and frequency resources of future activity of the MWS RAT. The UE may schedule communications of the WCN RAT based at least in part on the indication of the time and frequency resources of the future activity.

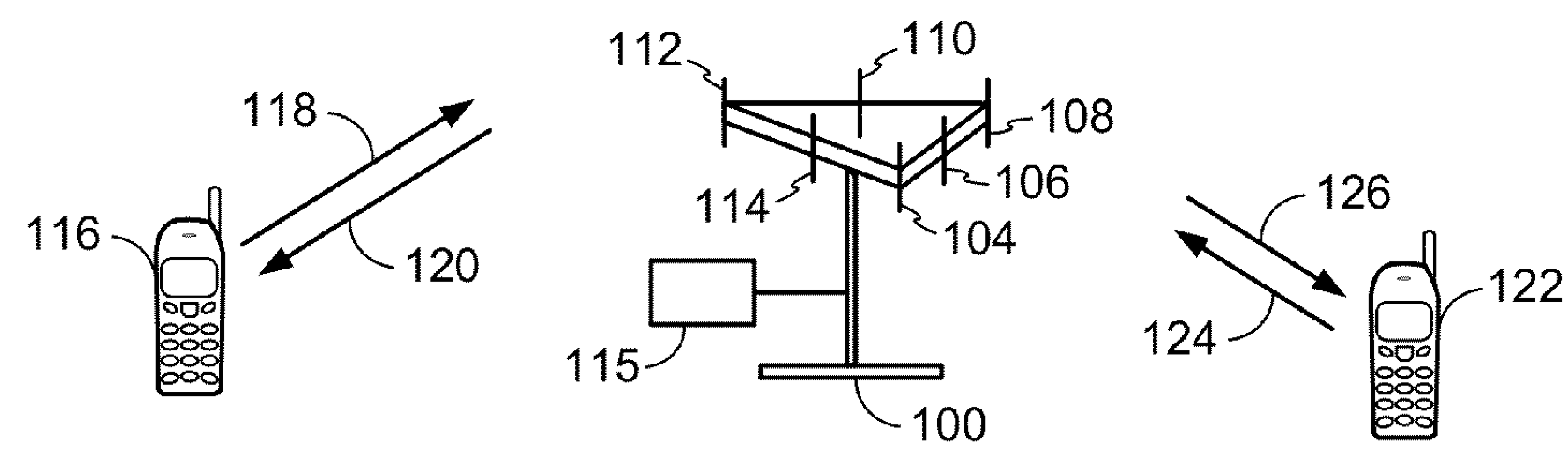
16 Claims, 16 Drawing Sheets



(56) **References Cited**

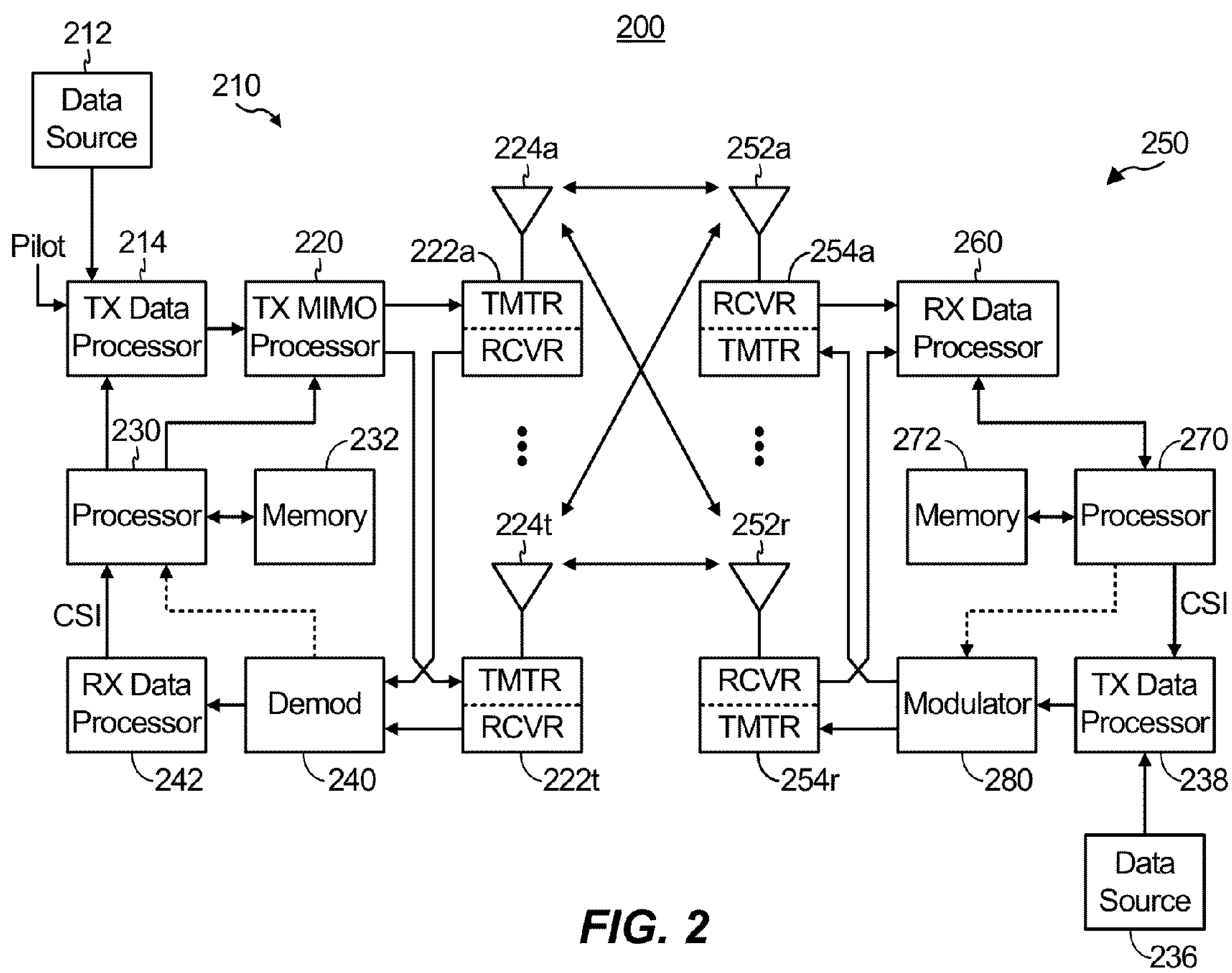
U.S. PATENT DOCUMENTS

2010/0304770	A1	12/2010	Wietfeldt et al.
2010/0316027	A1	12/2010	Rick et al.
2011/0237188	A1	9/2011	Sen
2011/0243047	A1	10/2011	Dayal et al.
2012/0071185	A1	3/2012	Dayal et al.
2013/0016635	A1	1/2013	Linsky et al.



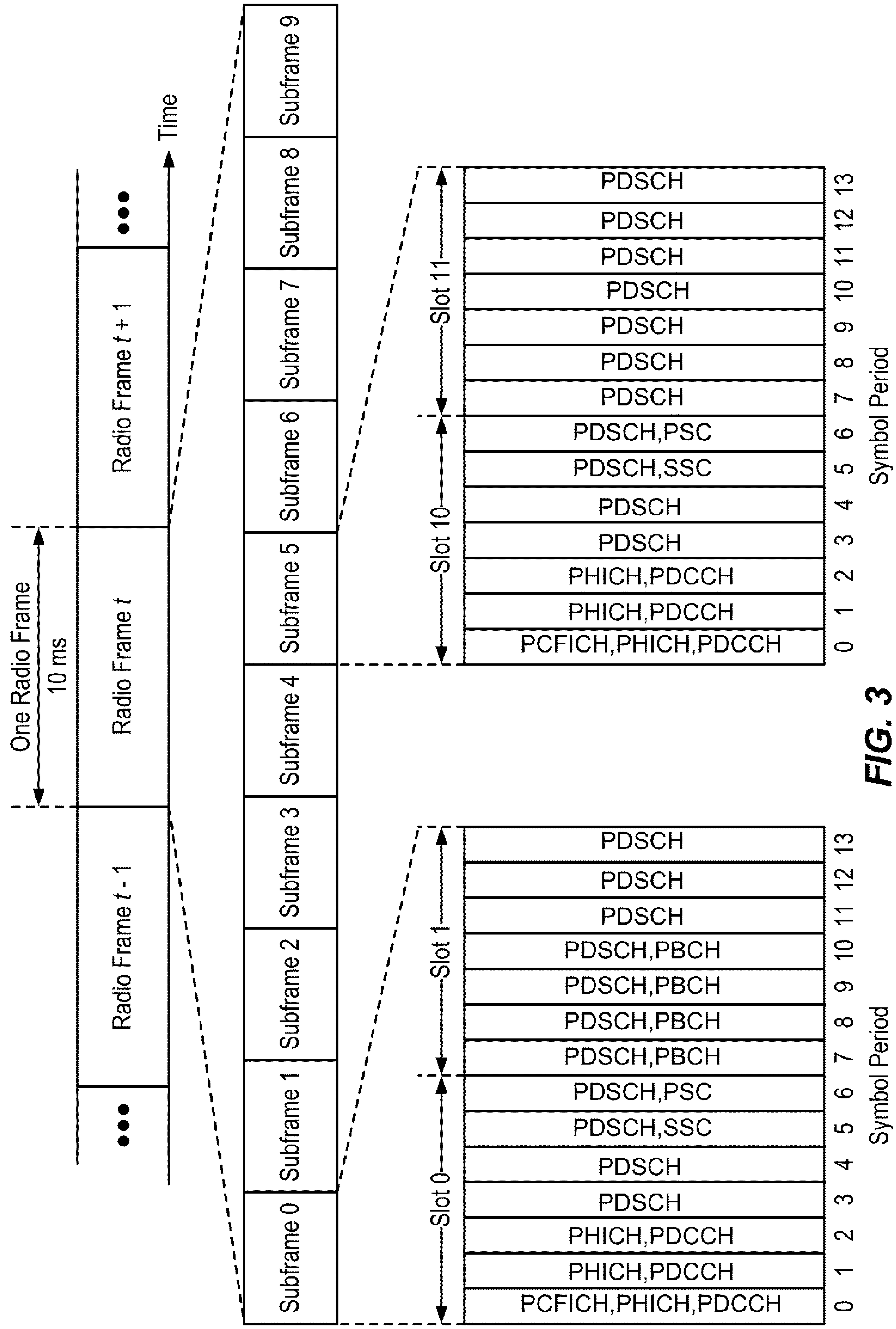
112
110
108
106
104
114
118
120
116
115
100
126
124
122

FIG. 1



200
212
Data Source
210
224a
252a
250
Pilot
214
TX Data Processor
220
TX MIMO Processor
222a
TMTR
RCVR
RCVR
TMTR
254a
260
RX Data Processor
230
Processor
232
Memory
224t
252r
272
Memory
270
Processor
CSI
RX Data Processor
Demod
TMTR
RCVR
RCVR
TMTR
Modulator
CSI
TX Data Processor
242
240
222t
254r
280
238
Data Source
236

FIG. 2



Time
One Radio Frame
10 ms
Radio Frame t - 1
Radio Frame t
Radio Frame t + 1
Subframe 0
Subframe 1
Subframe 2
Subframe 3
Subframe 4
Subframe 5
Subframe 6
Subframe 7
Subframe 8
Subframe 9
Slot 0
Slot 1
Slot 10
Slot 11
PCFICH,PHICH,PDCCH
PHICH,PDCCH
PHICH,PDCCH
PDSCH
PDSCH
PDSCH,SSC
PDSCH,PSC
PDSCH,PBCH
PDSCH,PBCH
PDSCH,PBCH
PDSCH,PBCH
PDSCH
PDSCH
PDSCH
PCFICH,PHICH,PDCCH
PHICH,PDCCH
PHICH,PDCCH
PDSCH
PDSCH
PDSCH,SSC
PDSCH,PSC
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
PDSCH
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Symbol Period

FIG. 3

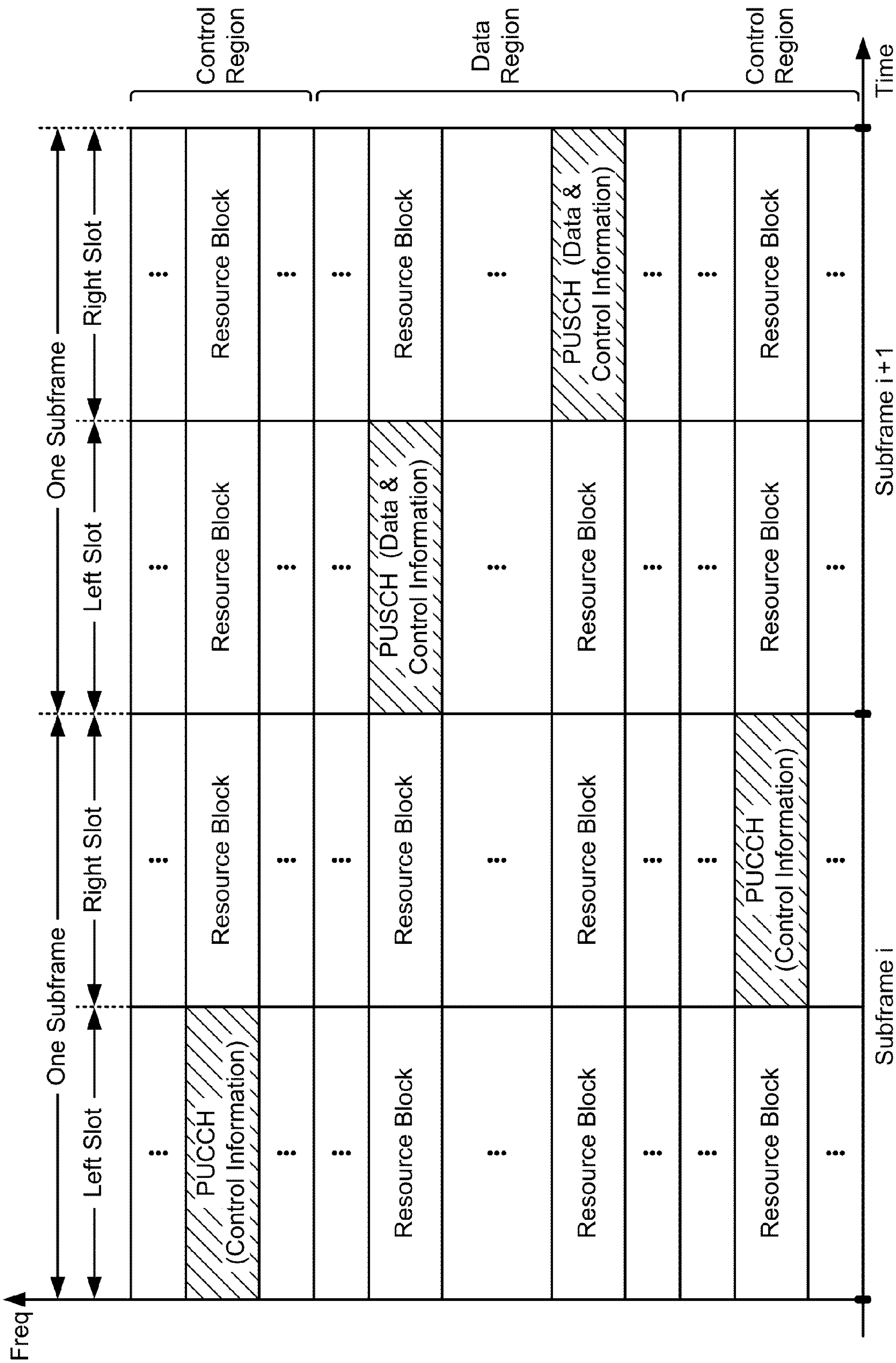
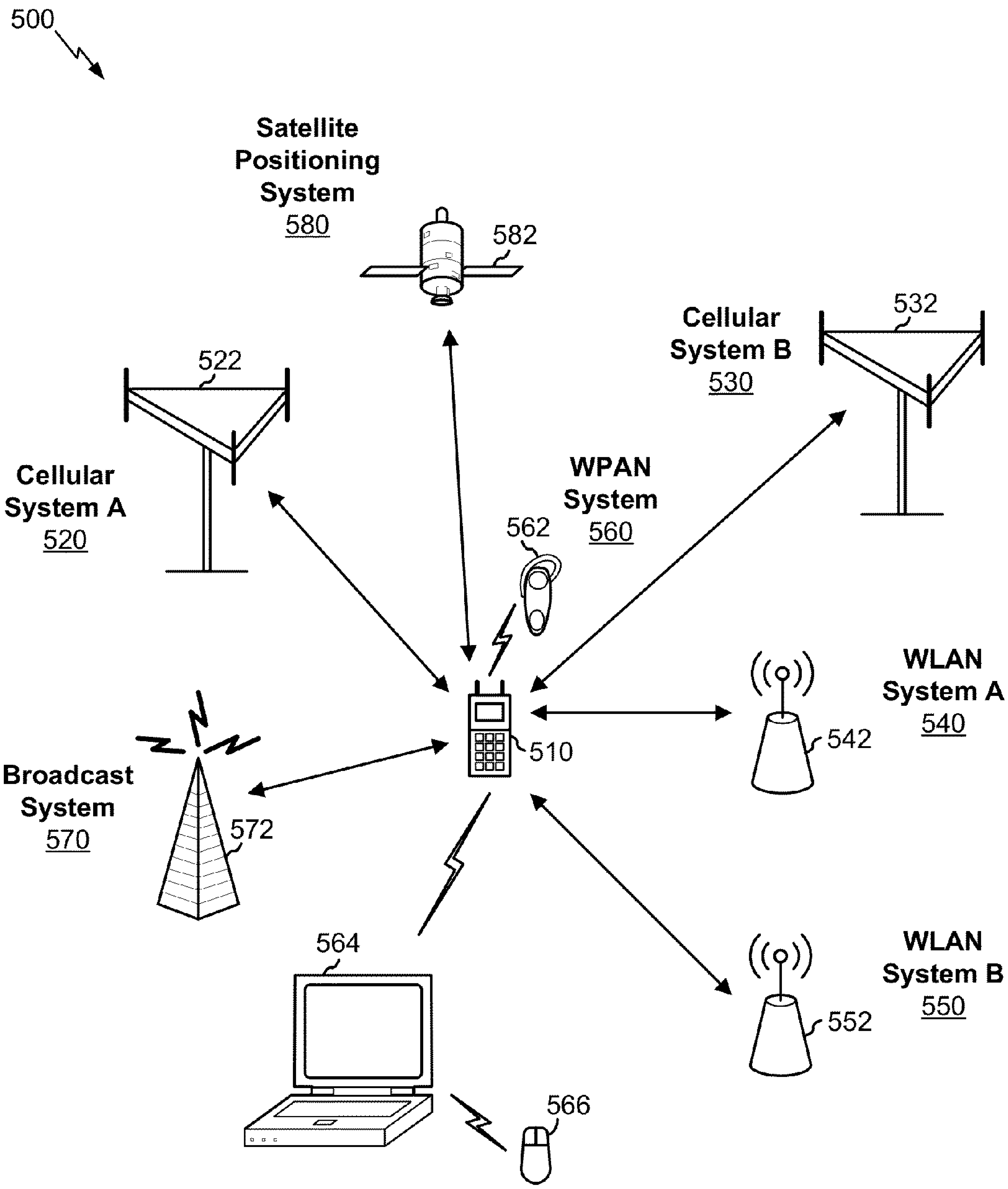

Freq
Time
One Subframe
One Subframe
Left Slot
Right Slot
Left Slot
Right Slot
Control Region
Data Region
Control Region
PUCCH (Control Information)
PUCCH (Control Information)
PUSCH (Data & Control Information)
PUSCH (Data & Control Information)
Resource Block
Subframe i
Subframe i+1

FIG. 4



500
Satellite Positioning System 580
582
Cellular System B 530
532
522
Cellular System A 520
WPAN System 560
562
WLAN System A 540
542
510
Broadcast System 570
572
564
WLAN System B 550
552
566

FIG. 5

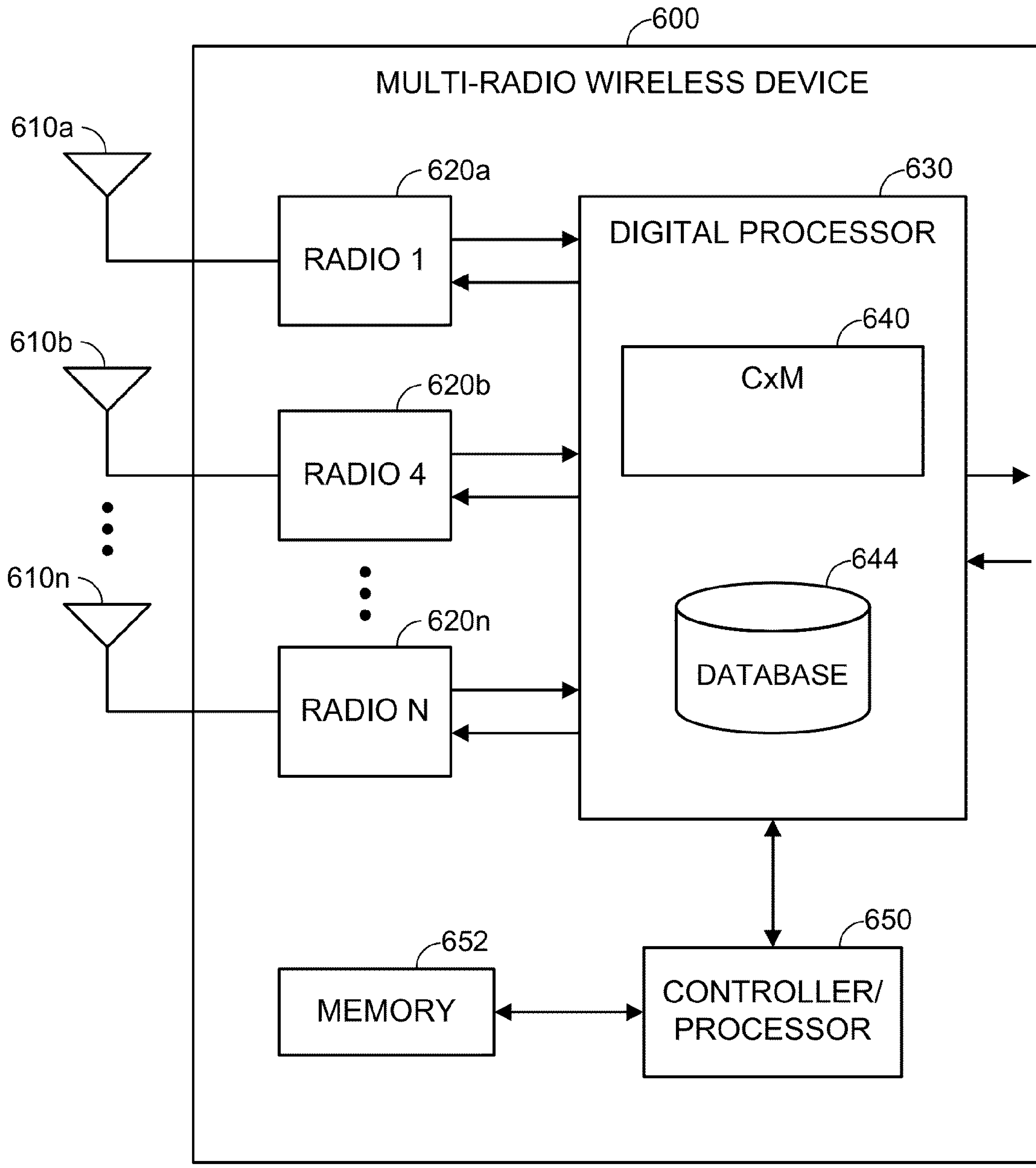

600
MULTI-RADIO WIRELESS DEVICE
610a
620a
630
RADIO 1
DIGITAL PROCESSOR
610b
640
620b
CxM
RADIO 4
610n
644
620n
DATABASE
RADIO N
652
650
MEMORY
CONTROLLER/
PROCESSOR

FIG. 6

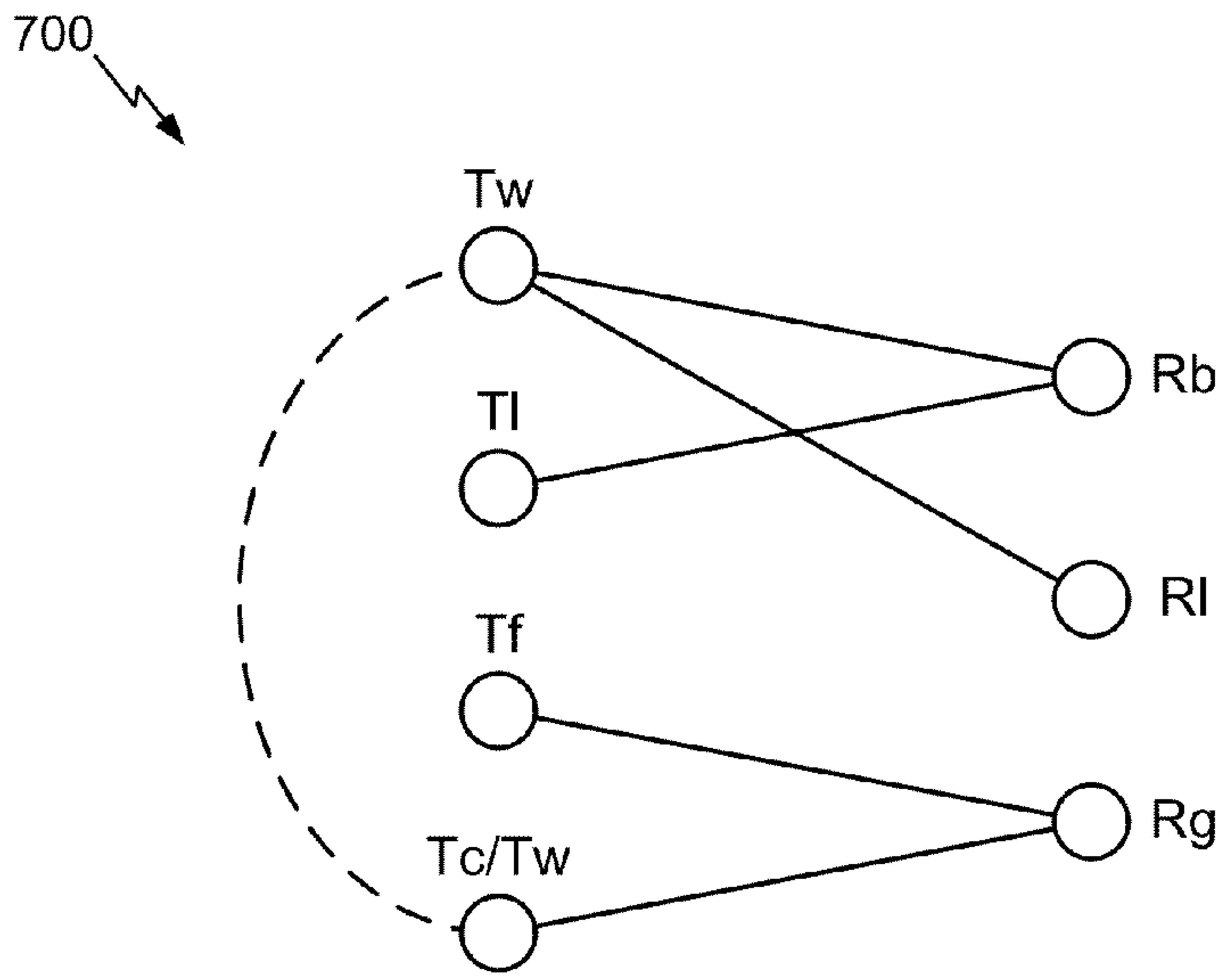

700
Tw
Rb
Tl
Rl
Tf
Rg
Tc/Tw

FIG. 7

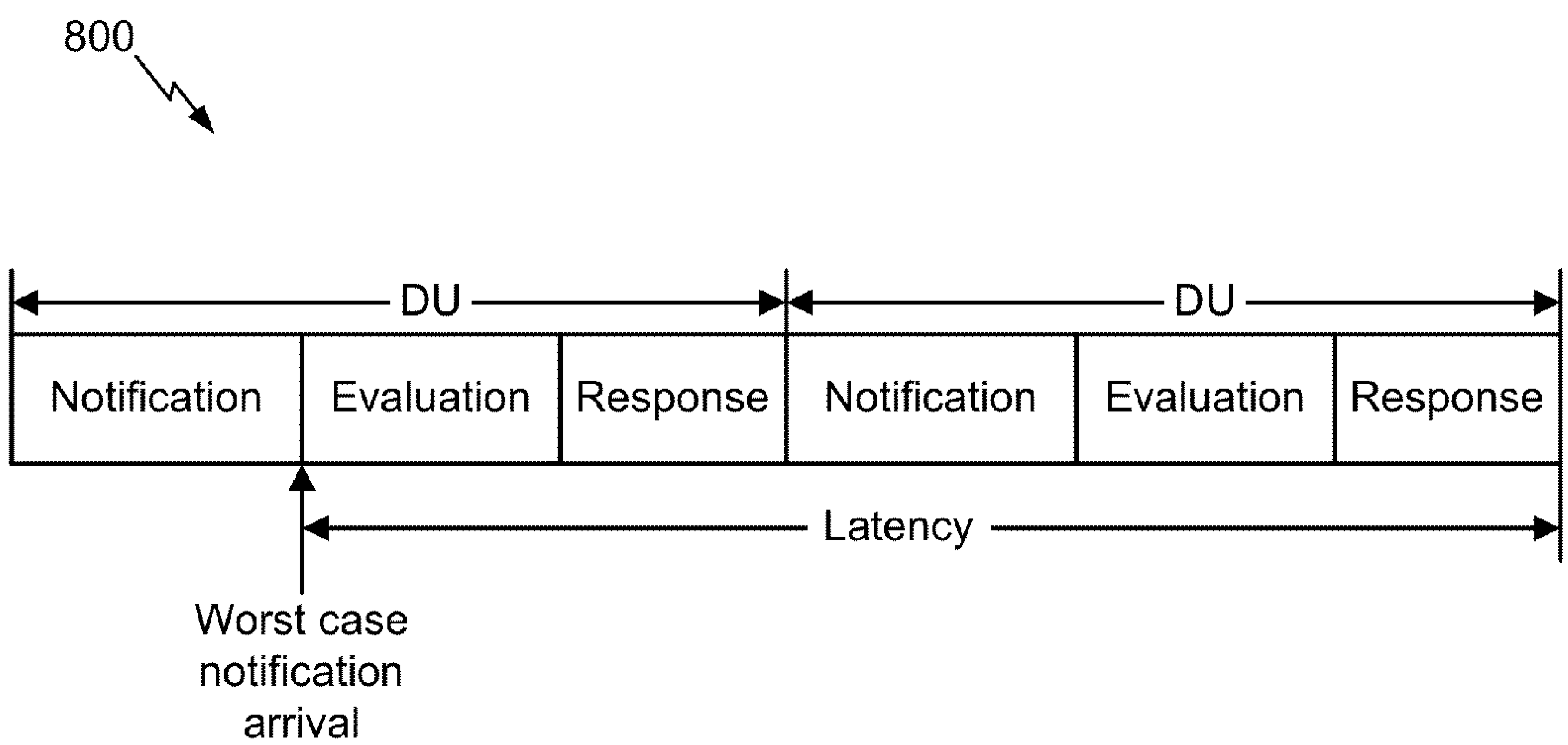

800
DU
DU
Notification
Evaluation
Response
Notification
Evaluation
Response
Latency
Worst case
notification
arrival

FIG. 8

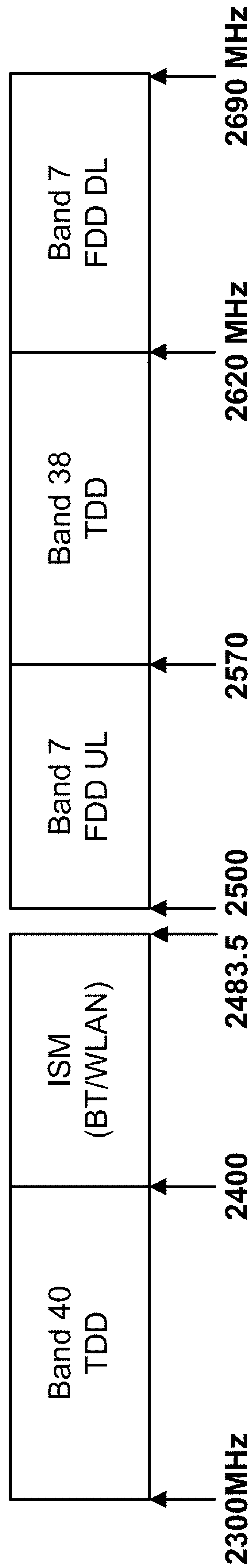

Band 40
TDD
ISM
(BT/WLAN)
Band 7
FDD UL
Band 38
TDD
Band 7
FDD DL
2300MHz
2400
2483.5
2500
2570
2620 MHz
2690 MHz

FIG. 9

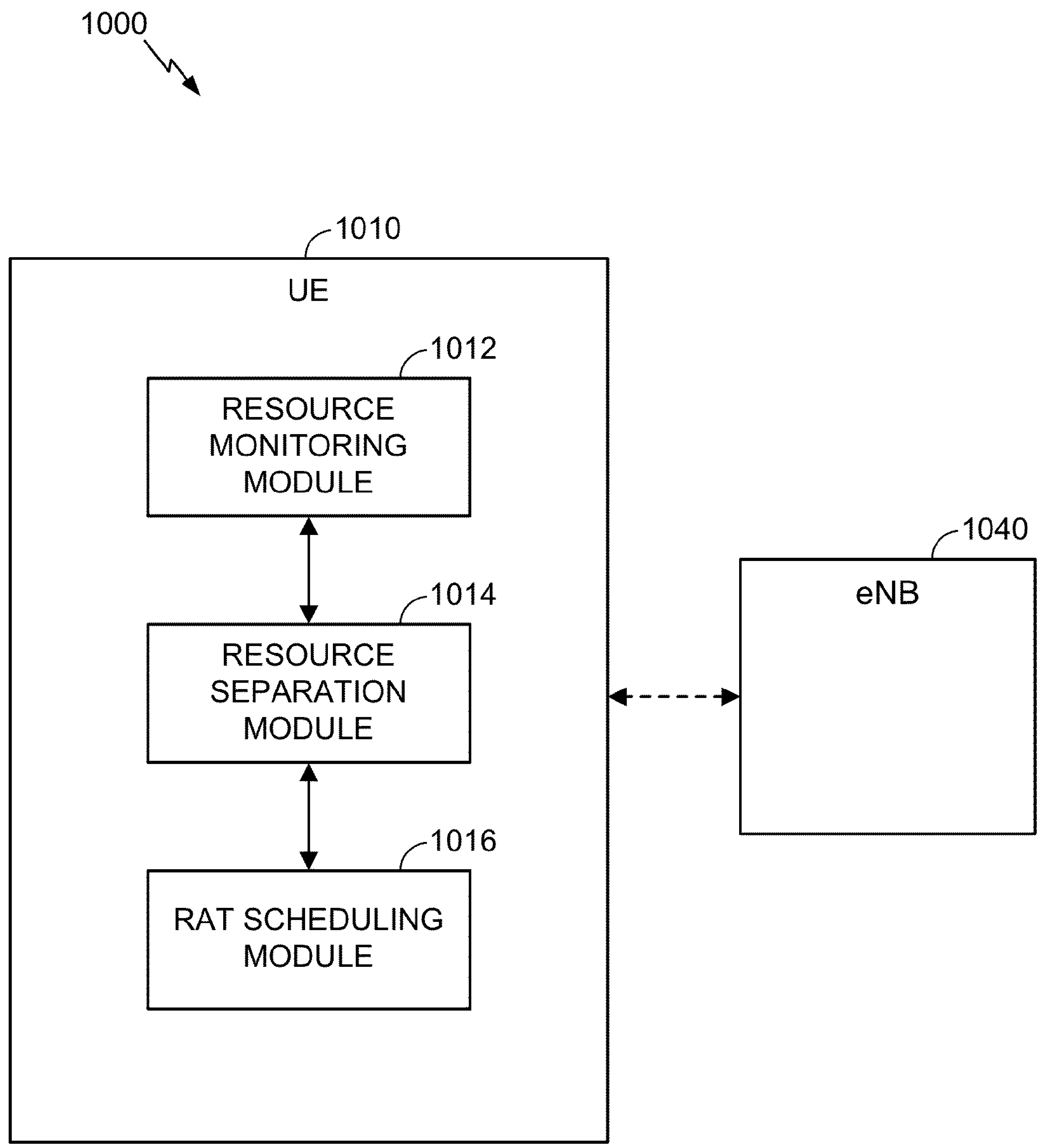

1000
1010
UE
1012
RESOURCE MONITORING MODULE
1014
RESOURCE SEPARATION MODULE
1016
RAT SCHEDULING MODULE
1040
eNB

FIG. 10

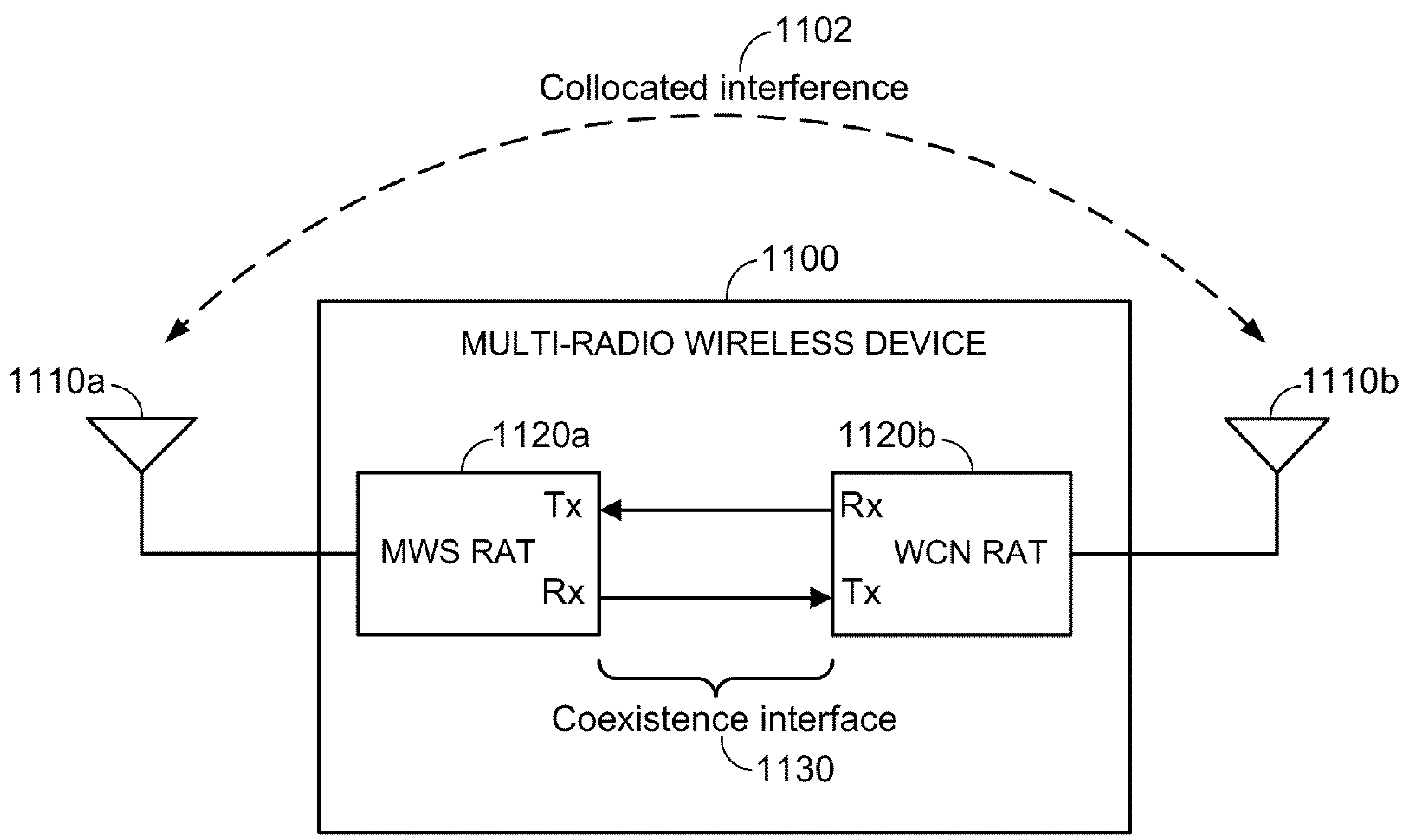

1102
Collocated interference
1100
MULTI-RADIO WIRELESS DEVICE
1110a
1110b
1120a
1120b
Tx
MWS RAT
Rx
Rx
WCN RAT
Tx
Coexistence interface
1130

FIG. 11

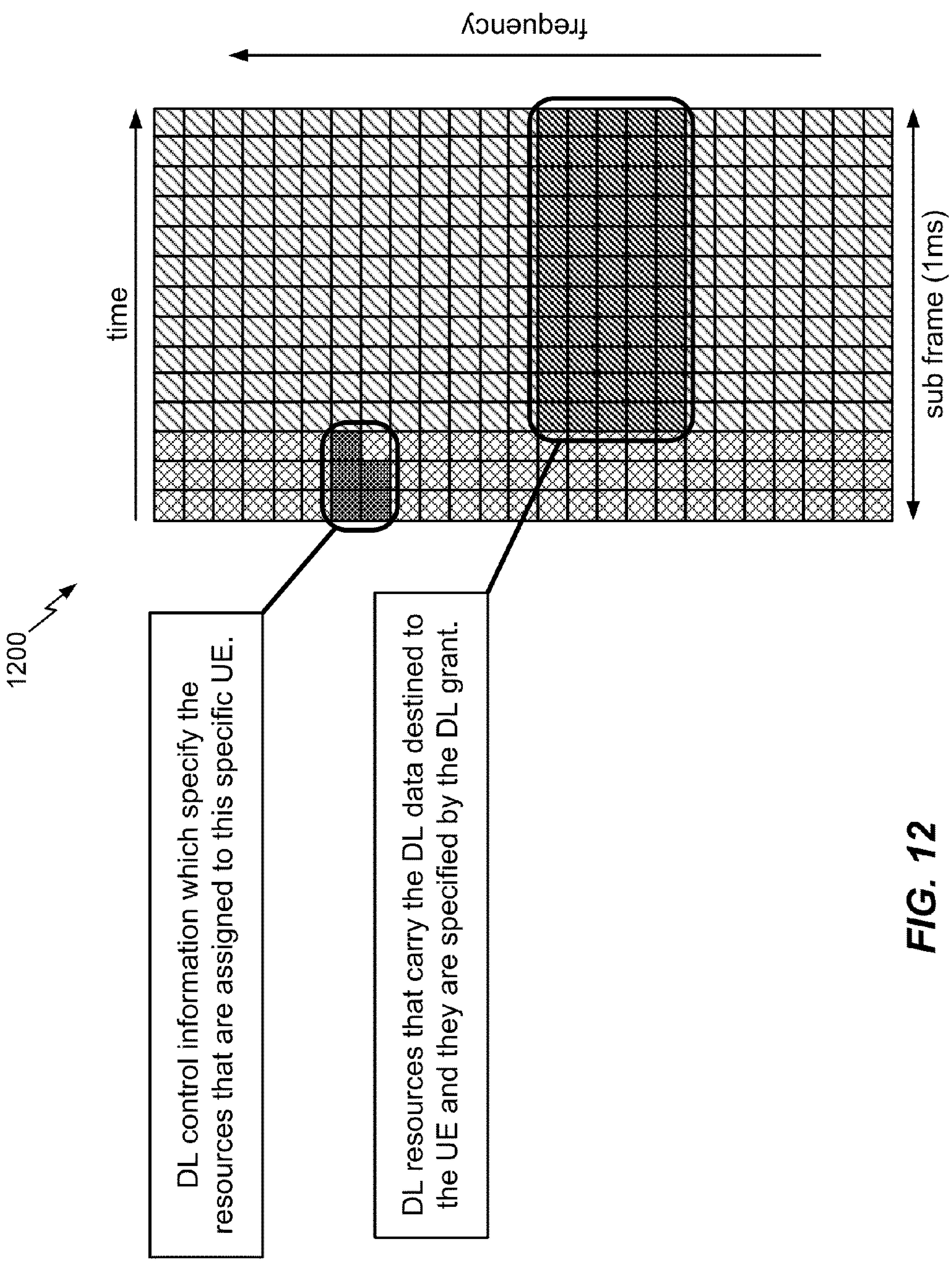

frequency
time
sub frame (1ms)
1200
DL control information which specify the resources that are assigned to this specific UE.
DL resources that carry the DL data destined to the UE and they are specified by the DL grant.

FIG. 12

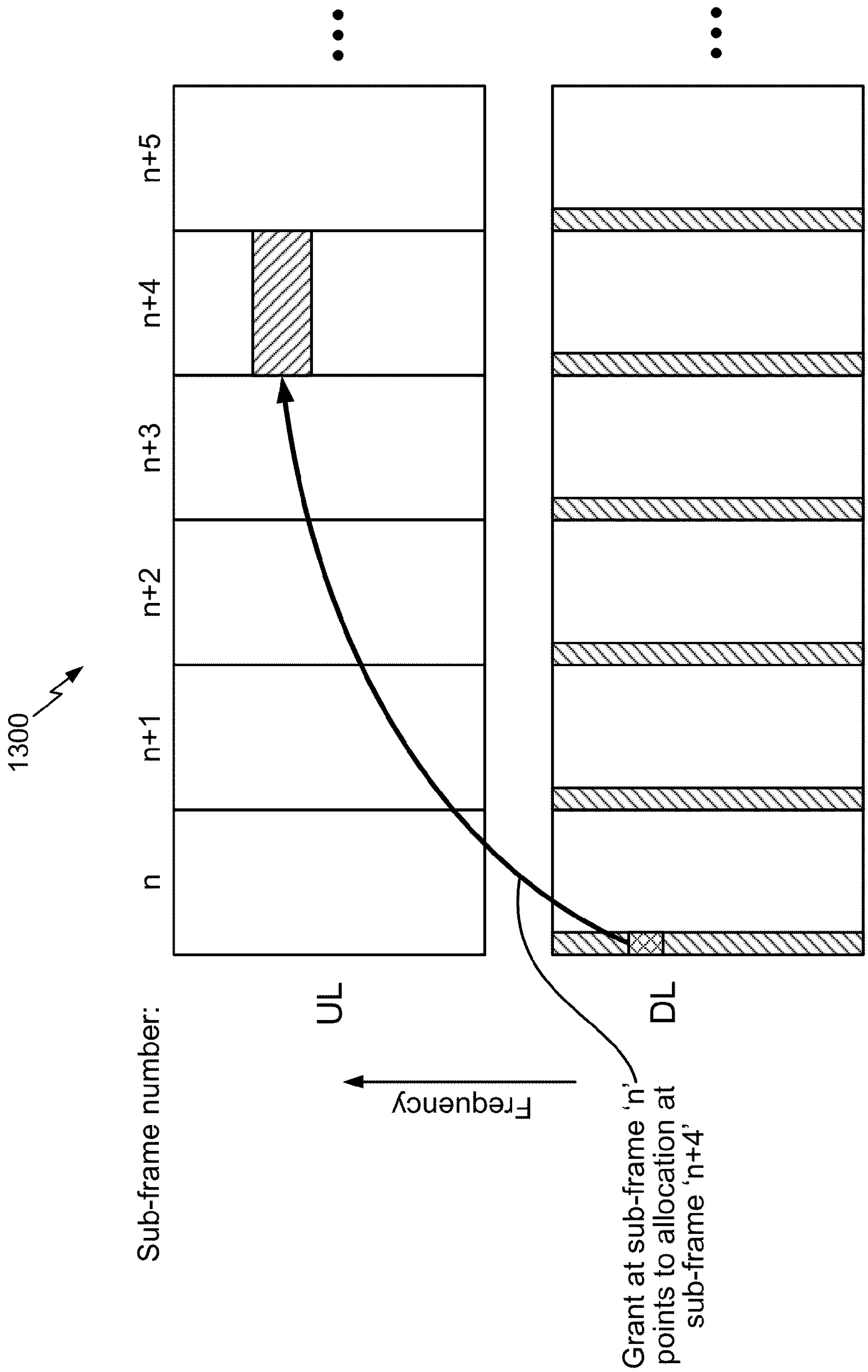

1300
Sub-frame number:
n
n+1
n+2
n+3
n+4
n+5
UL
DL
Frequency
Grant at sub-frame 'n' points to allocation at sub-frame 'n+4'

FIG. 13

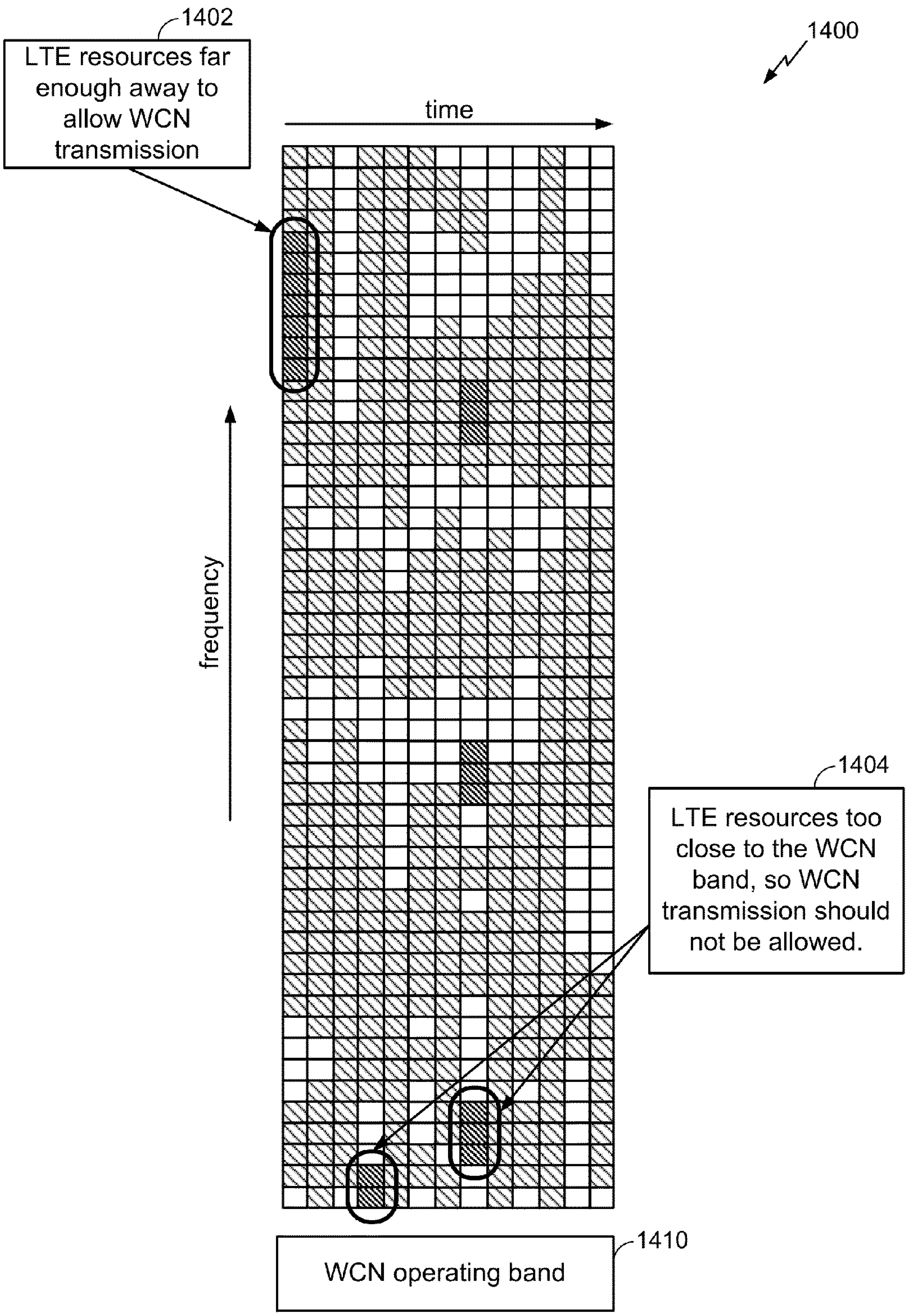

1402
LTE resources far enough away to allow WCN transmission
1400
time
frequency
1404
LTE resources too close to the WCN band, so WCN transmission should not be allowed.
WCN operating band
1410

FIG. 14

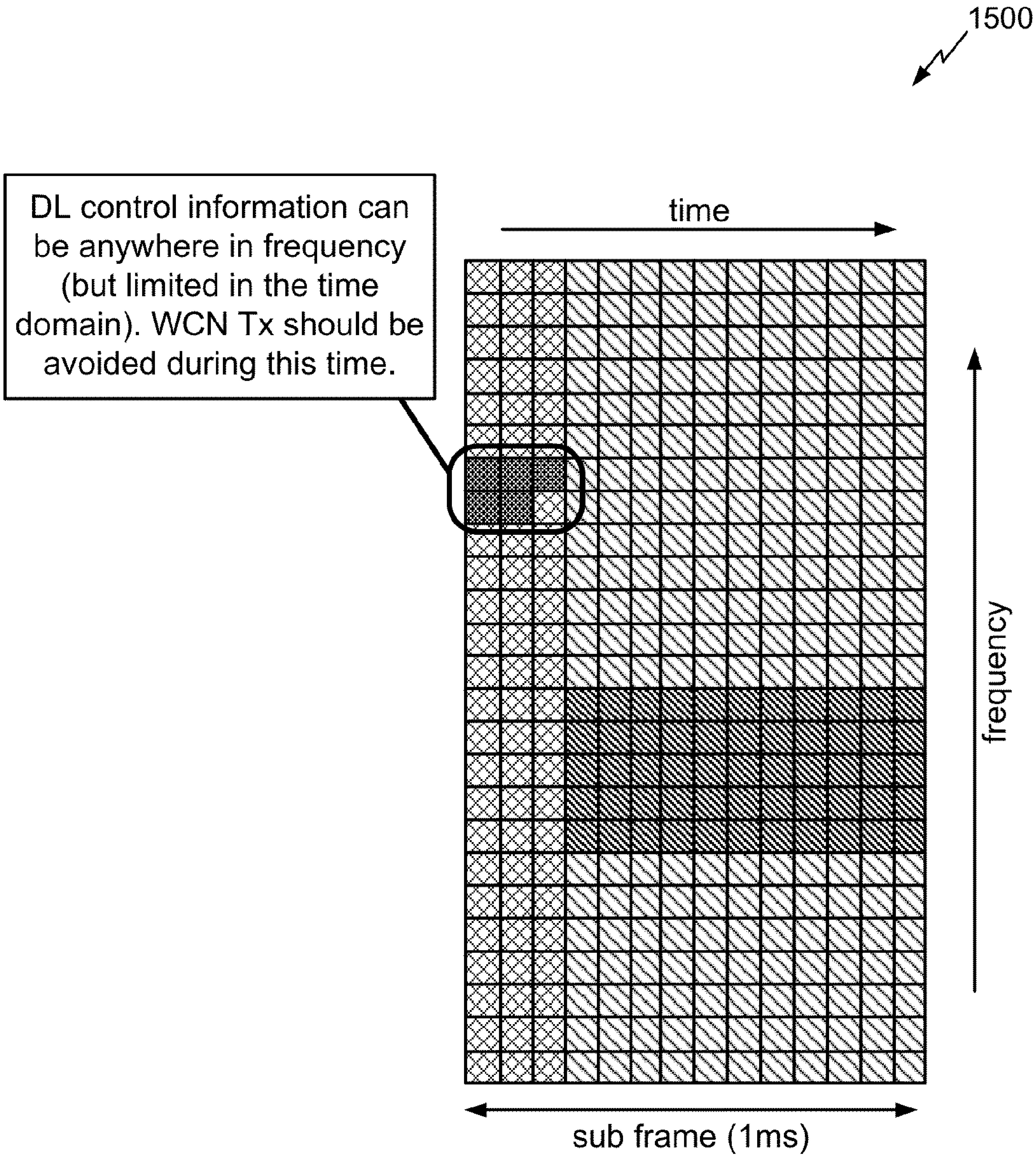

1500
DL control information can be anywhere in frequency (but limited in the time domain). WCN Tx should be avoided during this time.
time
frequency
sub frame (1ms)

FIG. 15

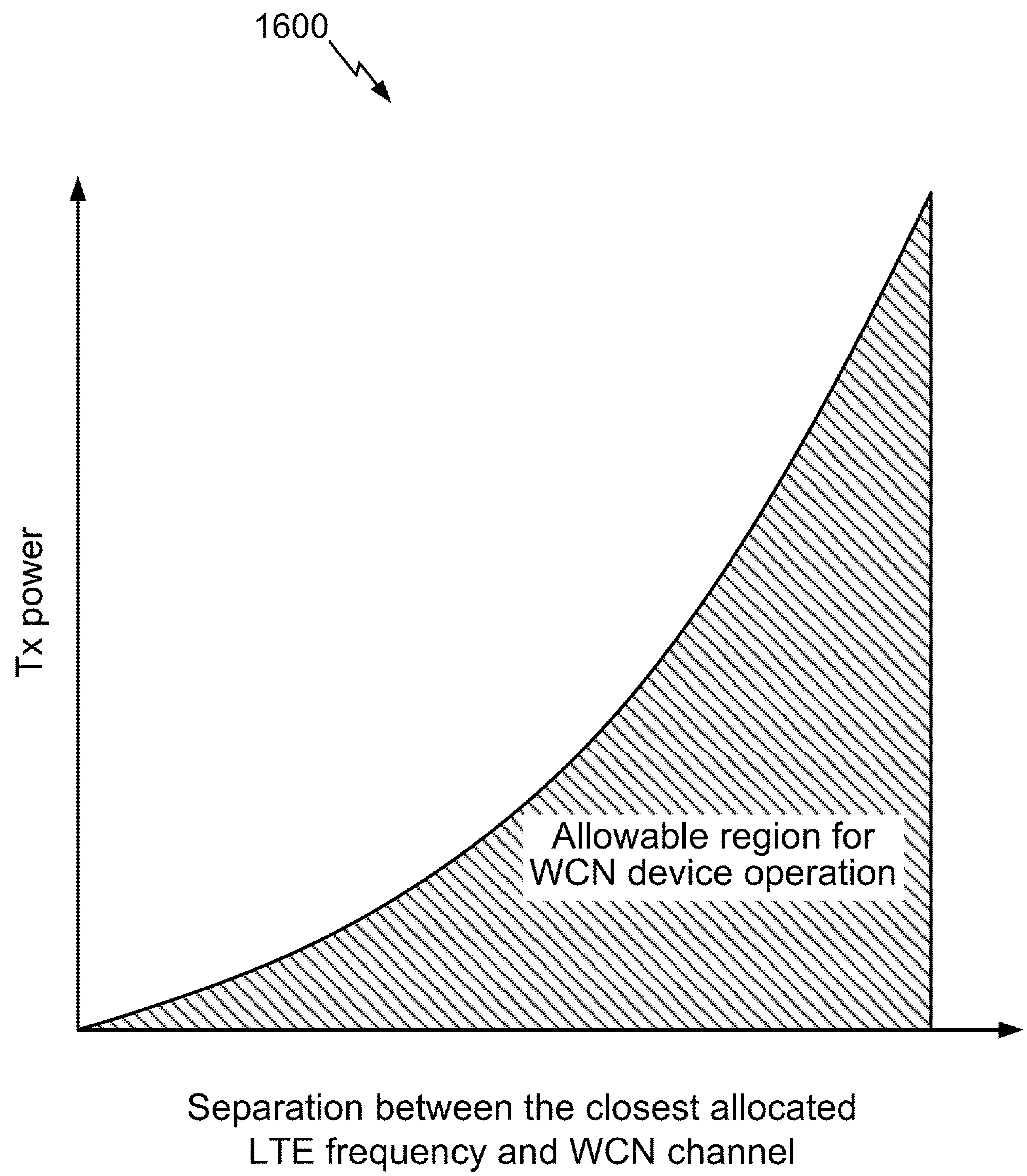

1600
Tx power
Allowable region for
WCN device operation
Separation between the closest allocated
LTE frequency and WCN channel

FIG. 16

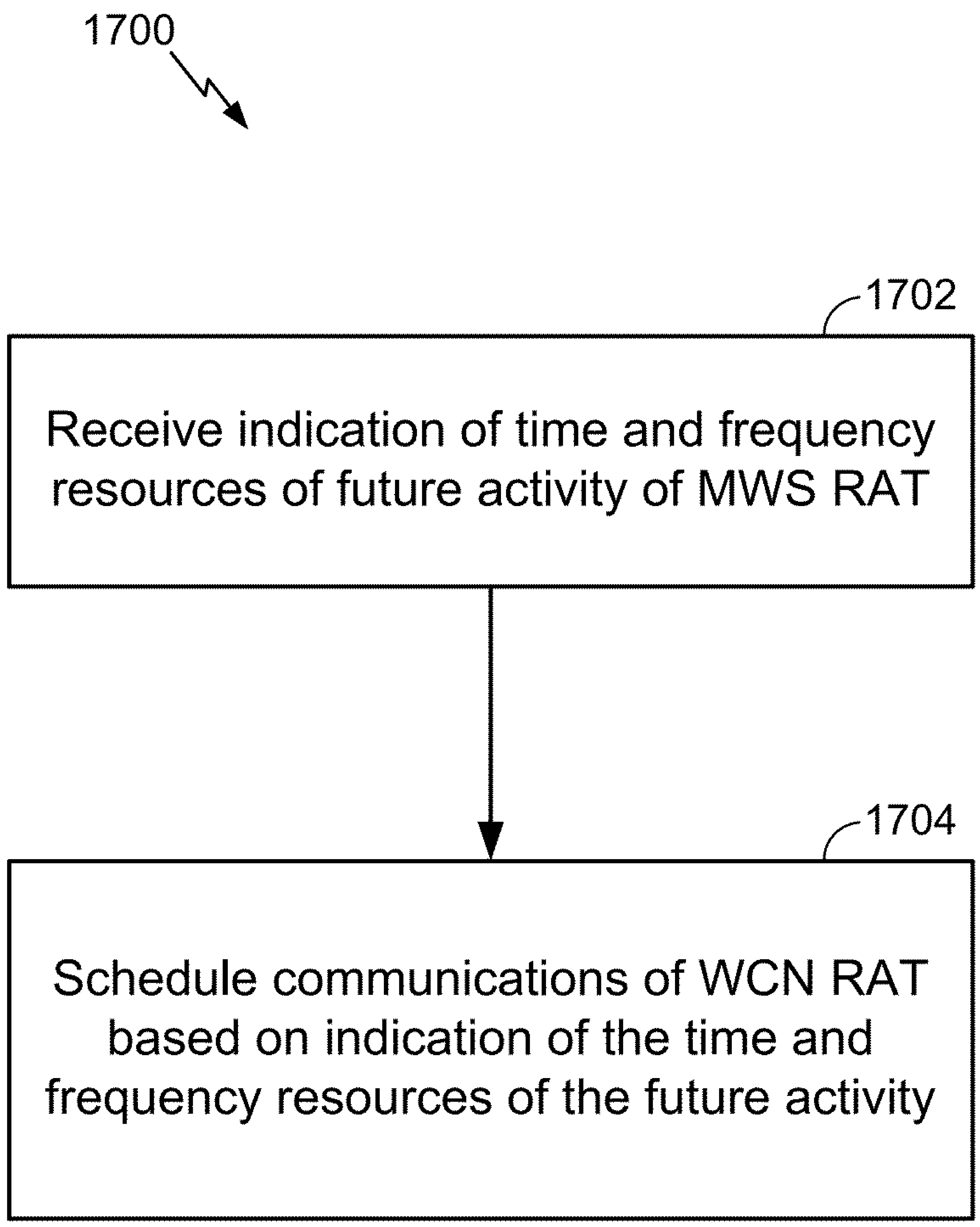

1700
1702
Receive indication of time and frequency resources of future activity of MWS RAT
1704
Schedule communications of WCN RAT based on indication of the time and frequency resources of the future activity

FIG. 17

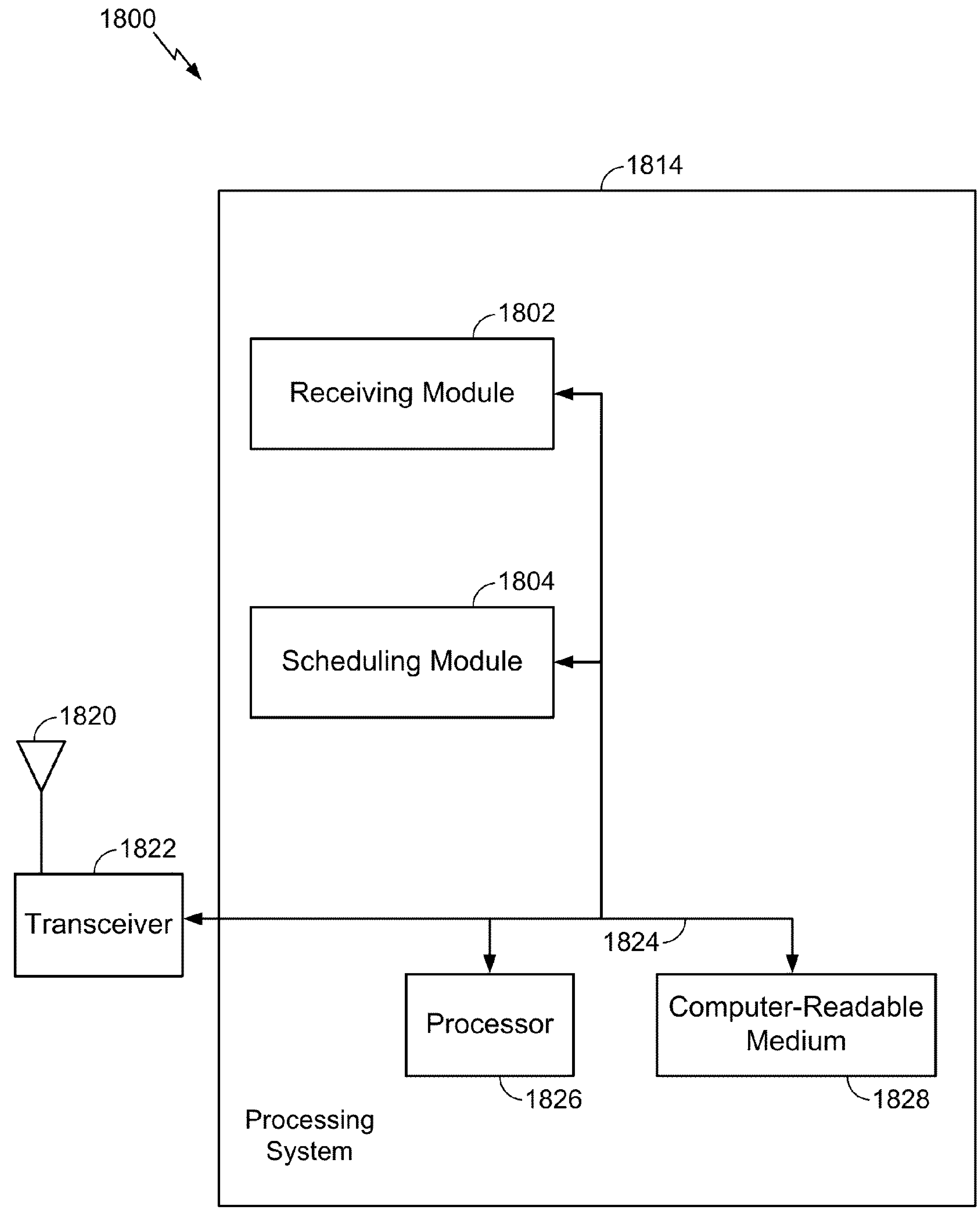

1800
1814
1802
Receiving Module
1804
Scheduling Module
1820
1822
Transceiver
1824
Processor
Computer-Readable Medium
1826
1828
Processing System

FIG. 18

TIME-FREQUENCY SCHEDULING TO IMPROVE MULTI-RADIO COEXISTENCE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 U.S.C. §119 (e) to U.S. Provisional Patent Application No. 61/692,152, entitled, TIME-FREQUENCY SCHEDULING TO IMPROVE MULTI-RADIO COEXISTENCE, filed on Aug. 22, 2012, in the names of BEHNAMFAR, et al., the disclosure of which is expressly incorporated by reference herein in its entirety.

BACKGROUND

1. Field

Aspects of the present disclosure relate generally to multi-radio techniques and, more specifically, to coexistence techniques for multi-radio devices.

2. Background

Wireless communication systems are widely deployed to provide various types of communication content such as voice, data, and so on. These systems may be multiple-access systems capable of supporting communication with multiple users by sharing the available system resources (e.g., bandwidth and transmit power). Examples of such multiple access systems include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, 3GPP Long Term Evolution (LTE) systems, and orthogonal frequency division multiple access (OFDMA) systems.

Generally, a wireless multiple-access communication system can simultaneously support communication for multiple wireless terminals. Each terminal communicates with one or more base stations via transmissions on the forward and reverse links. The forward link (or downlink) refers to the communication link from the base stations to the terminals, and the reverse link (or uplink) refers to the communication link from the terminals to the base stations. This communication link may be established via a single-in-single-out, multiple-in-single-out or a multiple-in-multiple out (MIMO) system.

Some conventional advanced devices include multiple radios for transmitting/receiving using different Radio Access Technologies (RATs). Examples of RATs include, e.g., Universal Mobile Telecommunications System (UMTS), Global System for Mobile Communications (GSM), cdma2000, WiMAX, WLAN (e.g., WiFi), Bluetooth, LTE, and the like.

An example mobile device includes an LTE User Equipment (UE), such as a fourth generation (4G) mobile phone. Such 4G phone may include various radios to provide a variety of functions for the user. For purposes of this example, the 4G phone includes an LTE radio for voice and data, an IEEE 802.11 (WiFi) radio, a Global Positioning System (GPS) radio, and a Bluetooth radio, where two of the above or all four may operate simultaneously. While the different radios provide useful functionalities for the phone, their inclusion in a single device gives rise to coexistence issues. Specifically, operation of one radio may in some cases interfere with operation of another radio through radiative, conductive, resource collision, and/or other interference mechanisms. Coexistence issues include such interference.

This is especially true for the LTE uplink channel, which is adjacent to the Industrial Scientific and Medical (ISM) band and may cause interference therewith. It is noted that Bluetooth and some Wireless LAN (WLAN) channels fall within the ISM band. In some instances, a Bluetooth error rate can become unacceptable when LTE is active in some channels of Band 7 or even Band 40 for some Bluetooth channel conditions. Even though there is no significant degradation to LTE, simultaneous operation with Bluetooth can result in disruption in voice services terminating in a Bluetooth headset. Such disruption may be unacceptable to the consumer. A similar issue exists when LTE transmissions interfere with GPS. Currently, there is no mechanism that can solve this issue since LTE by itself does not experience any degradation

With reference specifically to LTE, it is noted that a UE communicates with an evolved NodeB (eNB; e.g., a base station for a wireless communications network) to inform the eNB of interference seen by the UE on the downlink. Furthermore, the eNB may be able to estimate interference at the UE using a downlink error rate. In some instances, the eNB and the UE can cooperate to find a solution that reduces interference at the UE, even interference due to radios within the UE itself. However, in conventional LTE, the interference estimates regarding the downlink may not be adequate to comprehensively address interference.

In one instance, an LTE uplink signal interferes with a Bluetooth signal or WLAN signal. However, such interference is not reflected in the downlink measurement reports at the eNB. As a result, unilateral action on the part of the UE (e.g., moving the uplink signal to a different channel) may be thwarted by the eNB, which is not aware of the uplink coexistence issue and seeks to undo the unilateral action. For instance, even if the UE re-establishes the connection on a different frequency channel, the network can still handover the UE back to the original frequency channel that was corrupted by the in-device interference. This is a likely scenario because the desired signal strength on the corrupted channel may sometimes be higher than reflected in the measurement reports of the new channel based on Reference Signal Received Power (RSRP) to the eNB. Hence, a ping-pong effect of being transferred back and forth between the corrupted channel and the desired channel can happen if the eNB uses RSRP reports to make handover decisions.

Other unilateral action on the part of the UE, such as simply stopping uplink communications without coordination of the eNB may cause power loop malfunctions at the eNB. Additional issues that exist in conventional LTE include a general lack of ability on the part of the UE to suggest desired configurations as an alternative to configurations that have coexistence issues. For at least these reasons, uplink coexistence issues at the UE may remain unresolved for a long time period, degrading performance and efficiency for other radios of the UE.

SUMMARY

According to one aspect of the present disclosure, a method for wireless communication includes receiving an indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT). The method may also include scheduling communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity.

According to another aspect of the present disclosure, an apparatus for wireless communication includes means for receiving an indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT). The apparatus may also include means for scheduling communications of a wireless connec-

tivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity.

According to one aspect of the present disclosure, a computer program product for wireless communication in a wireless network includes a computer readable medium having non-transitory program code recorded thereon. The program code includes program code to receive an indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT). The program code also includes program code to schedule communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity.

According to one aspect of the present disclosure, an apparatus for wireless communication includes a memory and a processor(s) coupled to the memory. The processor(s) is configured to receive an indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT). The processor(s) is further configured to schedule communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity.

This has outlined, rather broadly, the features and technical advantages of the present disclosure in order that the detailed description that follows may be better understood. Additional features and advantages of the disclosure will be described below. It should be appreciated by those skilled in the art that this disclosure may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the teachings of the disclosure as set forth in the appended claims. The novel features, which are believed to be characteristic of the disclosure, both as to its organization and method of operation, together with further objects and advantages, will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, nature, and advantages of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout.

FIG. **1** illustrates a multiple access wireless communication system according to one aspect.

FIG. **2** is a block diagram of a communication system according to one aspect.

FIG. **3** illustrates an exemplary frame structure in downlink Long Term Evolution (LTE) communications.

FIG. **4** is a block diagram conceptually illustrating an exemplary frame structure in uplink Long Term Evolution (LTE) communications.

FIG. **5** illustrates an example wireless communication environment.

FIG. **6** is a block diagram of an example design for a multi-radio wireless device.

FIG. **7** is graph showing respective potential collisions between seven example radios in a given decision period.

FIG. **8** is a diagram showing operation of an example Coexistence Manager (C×M) over time.

FIG. **9** is a block diagram illustrating adjacent frequency bands.

FIG. **10** is a block diagram of a system for providing support within a wireless communication environment for multi-radio coexistence management according to one aspect of the present disclosure.

FIG. **11** is a block diagram of a multi-radio wireless device according to one aspect of the disclosure.

FIG. **12** is a graph illustrating downlink control information specifying the resource assigned to a specific device according to one aspect of the disclosure.

FIG. **13** is a timing diagram that shows an uplink grant message sent from the base station to the UE during the downlink control portion of subframe n.

FIG. **14** is a timing diagram that shows mobile wireless service (MWS) resources that are too close to a wireless connectivity network operating band, according to one aspect of the disclosure.

FIG. **15** provides a block diagram that shows another example of LTE communication resources that may result in altered ISM communication activity, according to one aspect of the disclosure.

FIG. **16** is a graph illustrating a relationship between transmission power and resource block separation in determining an allowable region for operation of wireless connectivity network (WCN) communications, according to one aspect of the disclosure.

FIG. **17** is a block diagram illustrating method for using dynamic resource allocation information in an MWS RAT to improve MWS and WCN radio access technology coexistence according to one aspect of the present disclosure.

FIG. **18** is a diagram illustrating an example of a hardware implementation for an apparatus employing a coexistence mitigation system.

DETAILED DESCRIPTION

Various aspects of the disclosure provide techniques to mitigate coexistence issues in multi-radio devices, where significant in-device coexistence problems can exist between, mobile wireless services (MWS) devices (e.g., LTE) and wireless network connectivity (WCN) devices that operate in the Industrial Scientific and Medical (ISM) bands (e.g., for BT/WLAN). As explained above, some coexistence issues persist because an eNB is not aware of interference on the UE side that is experienced by other radios. To reduce the interference and manage inter-radio coexistence, it is desirable to coordinate behavior of the radios to reduce the time one radio is receiving while another, potentially interfering, radio is transmitting. One aspect of the present disclosure uses information regarding dynamic resource allocation in the MWS RAT to improve MWS and WCN radio access technology coexistence.

The techniques described herein can be used for various wireless communication networks such as Code Division Multiple Access (CDMA) networks, Time Division Multiple Access (TDMA) networks, Frequency Division Multiple Access (FDMA) networks, Orthogonal FDMA (OFDMA) networks, Single-Carrier FDMA (SC-FDMA) networks, etc. The terms "networks" and "systems" are often used interchangeably. A CDMA network can implement a radio technology such as Universal Terrestrial Radio Access (UTRA), cdma2000, etc. UTRA includes Wideband-CDMA (W-CDMA) and Low Chip Rate (LCR). cdma2000 covers IS-2000, IS-95 and IS-856 standards. A TDMA network can implement a radio technology such as Global System for Mobile Communications (GSM). An OFDMA network can implement a radio technology such as Evolved UTRA (E-UTRA), IEEE 802.11, IEEE 802.16, IEEE 802.20, Flash-OFDM, etc. UTRA, E-UTRA, and GSM are part of Universal Mobile Telecommunication System (UMTS). Long Term Evolution (LTE) is an upcoming release of UMTS that uses E-UTRA. UTRA, E-UTRA, GSM, UMTS and LTE are described in documents from an organization named "3rd Generation Partnership Project" (3GPP). CDMA2000 is described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). These various radio technologies and standards are known in the art. For clarity, certain aspects of the techniques are described below for LTE, and LTE terminology is used in portions of the description below.

Single carrier frequency division multiple access (SC-FDMA), which utilizes single carrier modulation and frequency domain equalization is a technique that can be utilized with various aspects described herein. SC-FDMA has similar performance and essentially the same overall complexity as those of an OFDMA system. SC-FDMA signal has lower peak-to-average power ratio (PAPR) because of its inherent single carrier structure. SC-FDMA has drawn great attention, especially in the uplink communications where lower PAPR greatly benefits the mobile terminal in terms of transmit power efficiency. It is currently a working assumption for an uplink multiple access scheme in 3GPP Long Term Evolution (LTE), or Evolved UTRA.

Referring to FIG. **1**, a multiple access wireless communication system according to one aspect is illustrated. An evolved Node B **100** (eNB) includes a computer **115** that has processing resources and memory resources to manage the LTE communications by allocating resources and parameters, granting/denying requests from user equipment, and/or the like. The eNB **100** also has multiple antenna groups, one group including antenna **104** and antenna **106**, another group including antenna **108** and antenna **110**, and an additional group including antenna **112** and antenna **114**. In FIG. **1**, only two antennas are shown for each antenna group, however, more or fewer antennas can be utilized for each antenna group. A User Equipment (UE) **116** (also referred to as an Access Terminal (AT)) is in communication with antennas **112** and **114**, while antennas **112** and **114** transmit information to the UE **116** over an uplink (UL) **188**. The UE **122** is in communication with antennas **106** and **108**, while antennas **106** and **108** transmit information to the UE **122** over a downlink (DL) **126** and receive information from the UE **122** over an uplink **124**. In a frequency division duplex (FDD) system, communication links **118**, **120**, **124** and **126** can use different frequencies for communication. For example, the downlink **120** can use a different frequency than used by the uplink **118**.

Each group of antennas and/or the area in which they are designed to communicate is often referred to as a sector of the eNB. In this aspect, respective antenna groups are designed to communicate to UEs in a sector of the areas covered by the eNB **100**.

In communication over the downlinks **120** and **126**, the transmitting antennas of the eNB **100** utilize beamforming to improve the signal-to-noise ratio of the uplinks for the different UEs **116** and **122**. Also, an eNB using beamforming to transmit to UEs scattered randomly through its coverage causes less interference to UEs in neighboring cells than a UE transmitting through a single antenna to all its UEs.

An eNB can be a fixed station used for communicating with the terminals and can also be referred to as an access point, base station, or some other terminology. A UE can also be called an access terminal, a wireless communication device, terminal, or some other terminology.

FIG. **2** is a block diagram of an aspect of a transmitter system **210** (also known as an eNB) and a receiver system **250** (also known as a UE) in a MIMO system **200**. In some instances, both a UE and an eNB each have a transceiver that includes a transmitter system and a receiver system. At the transmitter system **210**, traffic data for a number of data streams is provided from a data source **212** to a transmit (TX) data processor **214**.

A MIMO system employs multiple (N_T) transmit antennas and multiple (N_R) receive antennas for data transmission. A MIMO channel formed by the N_T transmit and N_R receive antennas may be decomposed into N_S independent channels, which are also referred to as spatial channels, wherein $N_S \leq \min\{N_T, N_R\}$. Each of the N_S independent channels corresponds to a dimension. The MIMO system can provide improved performance (e.g., higher throughput and/or greater reliability) if the additional dimensionalities created by the multiple transmit and receive antennas are utilized.

A MIMO system supports time division duplex (TDD) and frequency division duplex (FDD) systems. In a TDD system, the uplink and downlink transmissions are on the same frequency region so that the reciprocity principle allows the estimation of the downlink channel from the uplink channel. This enables the eNB to extract transmit beamforming gain on the downlink when multiple antennas are available at the eNB.

In an aspect, each data stream is transmitted over a respective transmit antenna. The TX data processor **214** formats, codes, and interleaves the traffic data for each data stream based on a particular coding scheme selected for that data stream to provide coded data.

The coded data for each data stream can be multiplexed with pilot data using OFDM techniques. The pilot data is a known data pattern processed in a known manner and can be used at the receiver system to estimate the channel response. The multiplexed pilot and coded data for each data stream is then modulated (e.g., symbol mapped) based on a particular modulation scheme (e.g., BPSK, QPSK, M-PSK, or M-QAM) selected for that data stream to provide modulation symbols. The data rate, coding, and modulation for each data stream can be determined by instructions performed by a processor **230** operating with a memory **232**.

The modulation symbols for respective data streams are then provided to a TX MIMO processor **220**, which can further process the modulation symbols (e.g., for OFDM). The TX MIMO processor **220** then provides N_T modulation symbol streams to N_T transmitters (TMTR) **222***a* through **222***t*. In certain aspects, the TX MIMO processor **220** applies beamforming weights to the symbols of the data streams and to the antenna from which the symbol is being transmitted.

Each transmitter **222** receives and processes a respective symbol stream to provide one or more analog signals, and further conditions (e.g., amplifies, filters, and upconverts) the analog signals to provide a modulated signal suitable for transmission over the MIMO channel. N_T modulated signals from the transmitters **222***a* through **222***t* are then transmitted from N_T antennas **224***a* through **224***t*, respectively.

At a receiver system **250**, the transmitted modulated signals are received by N_R antennas **252***a* through **252***r* and the received signal from each antenna **252** is provided to a respective receiver (RCVR) **254***a* through **254***r*. Each receiver **254** conditions (e.g., filters, amplifies, and downconverts) a respective received signal, digitizes the conditioned signal to provide samples, and further processes the samples to provide a corresponding "received" symbol stream.

An RX data processor **260** then receives and processes the N_R received symbol streams from N_R receivers **254** based on a particular receiver processing technique to provide N_R "detected" symbol streams. The RX data processor **260** then demodulates, deinterleaves, and decodes each detected symbol stream to recover the traffic data for the data stream. The processing by the RX data processor **260** is complementary to the processing performed by the TX MIMO processor **220** and the TX data processor **214** at the transmitter system **210**.

A processor **270** (operating with a memory **272**) periodically determines which pre-coding matrix to use (discussed below). The processor **270** formulates an uplink message having a matrix index portion and a rank value portion.

The uplink message can include various types of information regarding the communication link and/or the received data stream. The uplink message is then processed by a TX data processor **238**, which also receives traffic data for a number of data streams from a data source **236**, modulated by a modulator **280**, conditioned by transmitters **254***a* through **254***r*, and transmitted back to the transmitter system **210**.

At the transmitter system **210**, the modulated signals from the receiver system **250** are received by antennas **224**, conditioned by receivers **222**, demodulated by a demodulator **240**, and processed by an RX data processor **242** to extract the uplink message transmitted by the receiver system **250**. The processor **230** then determines which pre-coding matrix to use for determining the beamforming weights, then processes the extracted message.

FIG. **3** is a block diagram conceptually illustrating an exemplary frame structure in downlink Long Term Evolution (LTE) communications. The transmission timeline for the downlink may be partitioned into units of radio frames. Each radio frame may have a predetermined duration (e.g., 10 milliseconds (ms)) and may be partitioned into 10 subframes with indices of 0 through 9. Each subframe may include two slots. Each radio frame may thus include 20 slots with indices of 0 through 19. Each slot may include L symbol periods, e.g., 7 symbol periods for a normal cyclic prefix (as shown in FIG. **3**) or 6 symbol periods for an extended cyclic prefix. The 2L symbol periods in each subframe may be assigned indices of 0 through 2L−1. The available time frequency resources may be partitioned into resource blocks. Each resource block may cover N subcarriers (e.g., 12 subcarriers) in one slot.

In LTE, an eNB may send a Primary Synchronization Signal (PSS) and a Secondary Synchronization Signal (SSS) for each cell in the eNB. The PSS and SSS may be sent in symbol periods 6 and 5, respectively, in each of subframes 0 and 5 of each radio frame with the normal cyclic prefix, as shown in FIG. **3**. The synchronization signals may be used by UEs for cell detection and acquisition. The eNB may send a Physical Broadcast Channel (PBCH) in symbol periods 0 to 3 in slot 1 of subframe 0. The PBCH may carry certain system information.

The eNB may send a Cell-specific Reference Signal (CRS) for each cell in the eNB. The CRS may be sent in symbols 0, 1, and 4 of each slot in case of the normal cyclic prefix, and in symbols 0, 1, and 3 of each slot in case of the extended cyclic prefix. The CRS may be used by UEs for coherent demodulation of physical channels, timing and frequency tracking, Radio Link Monitoring (RLM), Reference Signal Received Power (RSRP), and Reference Signal Received Quality (RSRQ) measurements, etc.

The eNB may send a Physical Control Format Indicator Channel (PCFICH) in the first symbol period of each subframe, as seen in FIG. **3**. The PCFICH may convey the number of symbol periods (M) used for control channels, where M may be equal to 1, 2 or 3 and may change from subframe to subframe. M may also be equal to 4 for a small system bandwidth, e.g., with less than 10 resource blocks. In the example shown in FIG. **3**, M=3. The eNB may send a Physical HARQ Indicator Channel (PHICH) and a Physical Downlink Control Channel (PDCCH) in the first M symbol periods of each subframe. The PDCCH and PHICH are also included in the first three symbol periods in the example shown in FIG. **3**. The PHICH may carry information to support Hybrid Automatic Repeat Request (HARQ). The PDCCH may carry information on resource allocation for UEs and control information for downlink channels. The eNB may send a Physical Downlink Shared Channel (PDSCH) in the remaining symbol periods of each subframe. The PDSCH may carry data for UEs scheduled for data transmission on the downlink. The various signals and channels in LTE are described in 3GPP TS 36.211, entitled "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation," which is publicly available.

The eNB may send the PSS, SSS and PBCH in the center 1.08 MHz of the system bandwidth used by the eNB. The eNB may send the PCFICH and PHICH across the entire system bandwidth in each symbol period in which these channels are sent. The eNB may send the PDCCH to groups of UEs in certain portions of the system bandwidth. The eNB may send the PDSCH to specific UEs in specific portions of the system bandwidth. The eNB may send the PSS, SSS, PBCH, PCFICH and PHICH in a broadcast manner to all UEs, may send the PDCCH in a unicast manner to specific UEs, and may also send the PDSCH in a unicast manner to specific UEs.

A number of resource elements may be available in each symbol period. Each resource element may cover one subcarrier in one symbol period and may be used to send one modulation symbol, which may be a real or complex value. Resource elements not used for a reference signal in each symbol period may be arranged into resource element groups (REGs). Each REG may include four resource elements in one symbol period. The PCFICH may occupy four REGs, which may be spaced approximately equally across frequency, in symbol period 0. The PHICH may occupy three REGs, which may be spread across frequency, in one or more configurable symbol periods. For example, the three REGs for the PHICH may all belong in symbol period 0 or may be spread in symbol periods 0, 1 and 2. The PDCCH may occupy 9, 18, 32 or 64 REGs, which may be selected from the available REGs, in the first M symbol periods. Only certain combinations of REGs may be allowed for the PDCCH.

A UE may know the specific REGs used for the PHICH and the PCFICH. The UE may search different combinations of REGs for the PDCCH. The number of combinations to search is typically less than the number of allowed combinations for the PDCCH. An eNB may send the PDCCH to the UE in any of the combinations that the UE will search.

FIG. **4** is a block diagram conceptually illustrating an exemplary frame structure in uplink Long Term Evolution (LTE) communications. The available Resource Blocks (RBs) for the uplink may be partitioned into a data section and a control section. The control section may be formed at the two edges of the system bandwidth and may have a configurable size. The resource blocks in the control section may be assigned to UEs for transmission of control information. The data section may include all resource blocks not included in the control section. The design in FIG. **4** results in the data section including contiguous subcarriers, which may allow a single UE to be assigned all of the contiguous subcarriers in the data section.

A UE may be assigned resource blocks in the control section to transmit control information to an eNB. The UE may also be assigned resource blocks in the data section to transmit data to the eNodeB. The UE may transmit control information in a Physical Uplink Control Channel (PUCCH) on the assigned resource blocks in the control section. The UE may transmit only data or both data and control information in a Physical Uplink Shared Channel (PUSCH) on the assigned resource blocks in the data section. An uplink transmission may span both slots of a subframe and may hop across frequency as shown in FIG. **4**.

The PSS, SSS, CRS, PBCH, PUCCH and PUSCH in LTE are described in 3GPP TS 36.211, entitled "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation," which is publicly available.

In an aspect, described herein are systems and methods for providing support within a wireless communication environment, such as a 3GPP LTE environment or the like, to facilitate multi-radio coexistence solutions.

Referring now to FIG. **5**, illustrated is an example wireless communication environment **500** in which various aspects described herein can function. The wireless communication environment **500** can include a wireless device **510**, which can be capable of communicating with multiple communication systems. These systems can include, for example, one or more cellular systems **520** and/or **530**, one or more WLAN systems **540** and/or **550**, one or more wireless personal area network (WPAN) systems **560**, one or more broadcast systems **570**, one or more satellite positioning systems **580**, other systems not shown in FIG. **5**, or any combination thereof. It should be appreciated that in the following description the terms "network" and "system" are often used interchangeably.

The cellular systems **520** and **530** can each be a CDMA, TDMA, FDMA, OFDMA, Single Carrier FDMA (SC-FDMA), or other suitable system. A CDMA system can implement a radio technology such as Universal Terrestrial Radio Access (UTRA), cdma2000, etc. UTRA includes Wideband CDMA (WCDMA) and other variants of CDMA. Moreover, cdma2000 covers IS-2000 (CDMA2000 1X), IS-95 and IS-856 (HRPD) standards. A TDMA system can implement a radio technology such as Global System for Mobile Communications (GSM), Digital Advanced Mobile Phone System (D-AMPS), etc. An OFDMA system can implement a radio technology such as Evolved UTRA (E-UTRA), Ultra Mobile Broadband (UMB), IEEE 802.16 (WiMAX), IEEE 802.20, Flash-OFDM®, etc. UTRA and E-UTRA are part of Universal Mobile Telecommunication System (UMTS). 3GPP Long Term Evolution (LTE) and LTE-Advanced (LTE-A) are new releases of UMTS that use E-UTRA. UTRA, E-UTRA, UMTS, LTE, LTE-A and GSM are described in documents from an organization named "3rd Generation Partnership Project" (3GPP). cdma2000 and UMB are described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). In an aspect, the cellular system **520** can include a number of base stations **522**, which can support bi-directional communication for wireless devices within their coverage. Similarly, the cellular system **530** can include a number of base stations **532** that can support bi-directional communication for wireless devices within their coverage.

WLAN systems **540** and **550** can respectively implement radio technologies such as IEEE 802.11 (WiFi), Hiperlan, etc. The WLAN system **540** can include one or more access points **542** that can support bi-directional communication. Similarly, the WLAN system **550** can include one or more access points **552** that can support bi-directional communication. The WPAN system **560** can implement a radio technology such as Bluetooth (BT), IEEE 802.15, etc. Further, the WPAN system **560** can support bi-directional communication for various devices such as wireless device **510**, a headset **562**, a computer **564**, a mouse **566**, or the like.

The broadcast system **570** can be a television (TV) broadcast system, a frequency modulation (FM) broadcast system, a digital broadcast system, etc. A digital broadcast system can implement a radio technology such as MediaFLO™, Digital Video Broadcasting for Handhelds (DVB-H), Integrated Services Digital Broadcasting for Terrestrial Television Broadcasting (ISDB-T), or the like. Further, the broadcast system **570** can include one or more broadcast stations **572** that can support one-way communication.

The satellite positioning system **580** can be the United States Global Positioning System (GPS), the European Galileo system, the Russian GLONASS system, the Quasi-Zenith Satellite System (QZSS) over Japan, the Indian Regional Navigational Satellite System (IRNSS) over India, the Beidou system over China, and/or any other suitable system. Further, the satellite positioning system **580** can include a number of satellites **582** that transmit signals for position determination.

In an aspect, the wireless device **510** can be stationary or mobile and can also be referred to as a user equipment (UE), a mobile station, a mobile equipment, a terminal, an access terminal, a subscriber unit, a station, etc. The wireless device **510** can be cellular phone, a personal digital assistance (PDA), a wireless modem, a handheld device, a laptop computer, a cordless phone, a wireless local loop (WLL) station, etc. In addition, a wireless device **510** can engage in two-way communication with the cellular system **520** and/or **530**, the WLAN system **540** and/or **550**, devices with the WPAN system **560**, and/or any other suitable systems(s) and/or devices(s). The wireless device **510** can additionally or alternatively receive signals from the broadcast system **570** and/or satellite positioning system **580**. In general, it can be appreciated that the wireless device **510** can communicate with any number of systems at any given moment. Also, the wireless device **510** may experience coexistence issues among various ones of its constituent radio devices that operate at the same time. Accordingly, device **510** includes a coexistence manager (C×M, not shown) that has a functional module to detect and mitigate coexistence issues, as explained further below.

Turning next to FIG. **6**, a block diagram is provided that illustrates an example design for a multi-radio wireless device **600** and may be used as an implementation of the radio **510** of FIG. **5**. As FIG. **6** illustrates, the wireless device **600** can include N radios **620*a*** through **620*n***, which can be coupled to N antennas **610*a*** through **610*n***, respectively, where N can be any integer value. It should be appreciated, however, that respective radios **620** can be coupled to any number of antennas **610** and that multiple radios **620** can also share a given antenna **610**.

In general, a radio **620** can be a unit that radiates or emits energy in an electromagnetic spectrum, receives energy in an electromagnetic spectrum, or generates energy that propagates via conductive means. By way of example, a radio **620** can be a unit that transmits a signal to a system or a device or a unit that receives signals from a system or device. Accordingly, it can be appreciated that a radio **620** can be utilized to support wireless communication. In another example, a radio **620** can also be a unit (e.g., a screen on a computer, a circuit board, etc.) that emits noise, which can impact the performance of other radios. Accordingly, it can be further appreciated that a radio **620** can also be a unit that emits noise and interference without supporting wireless communication.

In an aspect, respective radios **620** can support communication with one or more systems. Multiple radios **620** can additionally or alternatively be used for a given system, e.g., to transmit or receive on different frequency bands (e.g., cellular and PCS bands).

In another aspect, a digital processor **630** can be coupled to radios **620***a* through **620***n* and can perform various functions, such as processing for data being transmitted or received via the radios **620**. The processing for each radio **620** can be dependent on the radio technology supported by that radio and can include encryption, encoding, modulation, etc., for a transmitter; demodulation, decoding, decryption, etc., for a receiver, or the like. In one example, the digital processor **630** can include a coexistence manager (C×M) **640** that can control operation of the radios **620** in order to improve the performance of the wireless device **600** as generally described herein. The coexistence manager **640** can have access to a database **644**, which can store information used to control the operation of the radios **620**. As explained further below, the coexistence manager **640** can be adapted for a variety of techniques to decrease interference between the radios. In one example, the coexistence manager **640** requests a measurement gap pattern or DRX cycle that allows an ISM radio to communicate during periods of LTE inactivity.

For simplicity, digital processor **630** is shown in FIG. **6** as a single processor. However, it should be appreciated that the digital processor **630** can include any number of processors, controllers, memories, etc. In one example, a controller/processor **650** can direct the operation of various units within the wireless device **600**. Additionally or alternatively, a memory **652** can store program codes and data for the wireless device **600**. The digital processor **630**, controller/processor **650**, and memory **652** can be implemented on one or more integrated circuits (ICs), application specific integrated circuits (ASICs), etc. By way of specific, non-limiting example, the digital processor **630** can be implemented on a Mobile Station Modem (MSM) ASIC.

In an aspect, the coexistence manager **640** can manage operation of respective radios **620** utilized by wireless device **600** in order to avoid interference and/or other performance degradation associated with collisions between respective radios **620**. coexistence manager **640** may perform one or more processes, such as those illustrated in FIG. **17**. By way of further illustration, a graph **700** in FIG. **7** represents respective potential collisions between seven example radios in a given decision period. In the example shown in graph **700**, the seven radios include a WLAN transmitter (Tw), an LTE transmitter (Tl), an FM transmitter (Tf), a GSM/WCDMA transmitter (Tc/Tw), an LTE receiver (Rl), a Bluetooth receiver (Rb), and a GPS receiver (Rg). The four transmitters are represented by four nodes on the left side of the graph **700**. The four receivers are represented by three nodes on the right side of the graph **700**.

A potential collision between a transmitter and a receiver is represented on the graph **700** by a branch connecting the node for the transmitter and the node for the receiver. Accordingly, in the example shown in the graph **700**, collisions may exist between (1) the WLAN transmitter (Tw) and the Bluetooth receiver (Rb); (2) the LTE transmitter (Tl) and the Bluetooth receiver (Rb); (3) the WLAN transmitter (Tw) and the LTE receiver (Rl); (4) the FM transmitter (Tf) and the GPS receiver (Rg); (5) a WLAN transmitter (Tw), a GSM/WCDMA transmitter (Tc/Tw), and a GPS receiver (Rg).

In one aspect, an example coexistence manager **640** can operate in time in a manner such as that shown by diagram **800** in FIG. **8**. As diagram **800** illustrates, a timeline for coexistence manager operation can be divided into Decision Units (DUs), which can be any suitable uniform or non-uniform length (e.g., 100 μs) where notifications are processed, and a response phase (e.g., 20 μs) where commands are provided to various radios **620** and/or other operations are performed based on actions taken in the evaluation phase. In one example, the timeline shown in the diagram **800** can have a latency parameter defined by a worst case operation of the timeline, e.g., the timing of a response in the case that a notification is obtained from a given radio immediately following termination of the notification phase in a given DU.

As shown in FIG. **9**, Long Term Evolution (LTE) in band 7 (for frequency division duplex (FDD) uplink), band 40 (for time division duplex (TDD) communication), and band 38 (for TDD downlink) is adjacent to the 2.4 GHz Industrial Scientific and Medical (ISM) band used by Bluetooth (BT) and Wireless Local Area Network (WLAN) technologies. Frequency planning for these bands is such that there is limited or no guard band permitting traditional filtering solutions to avoid interference at adjacent frequencies. For example, a 20 MHz guard band exists between ISM and band 7, but no guard band exists between ISM and band 40.

To be compliant with appropriate standards, communication devices operating over a particular band are to be operable over the entire specified frequency range. For example, in order to be LTE compliant, a mobile station/user equipment should be able to communicate across the entirety of both band 40 (2300-2400 MHz) and band 7 (2500-2570 MHz) as defined by the 3rd Generation Partnership Project (3GPP). Without a sufficient guard band, devices employ filters that overlap into other bands causing band interference. Because band 40 filters are 100 MHz wide to cover the entire band, the rollover from those filters crosses over into the ISM band causing interference. Similarly, ISM devices that use the entirety of the ISM band (e.g., from 2401 through approximately 2480 MHz) will employ filters that rollover into the neighboring band 40 and band 7 and may cause interference.

In-device coexistence problems can exist with respect to a UE between resources such as, for example, LTE and ISM bands (e.g., for Bluetooth/WLAN). In current LTE implementations, any interference issues to LTE are reflected in the downlink measurements (e.g., Reference Signal Received Quality (RSRQ) metrics, etc.) reported by a UE and/or the downlink error rate which the eNB can use to make inter-frequency or inter-RAT handoff decisions to, e.g., move LTE to a channel or RAT with no coexistence issues. However, it can be appreciated that these existing techniques will not work if, for example, the LTE uplink is causing interference to Bluetooth/WLAN but the LTE downlink does not see any interference from Bluetooth/WLAN. More particularly, even if the UE autonomously moves itself to another channel on the uplink, the eNB can in some cases handover the UE back to the problematic channel for load balancing purposes. In any case, it can be appreciated that existing techniques do not facilitate use of the bandwidth of the problematic channel in the most efficient way.

Turning now to FIG. **10**, a block diagram of a system **1000** for providing support within a wireless communication environment for multi-radio coexistence management is illustrated. In an aspect, the system **1000** can include one or more UEs **1010** and/or eNBs **1040**, which can engage in uplink and/or downlink communications, and/or any other suitable communication with each other and/or any other entities in the system **1000**. In one example, the UE **1010** and/or eNB **1040** can be operable to communicate using a variety resources, including frequency channels and sub-bands, some of which can potentially be colliding with other radio resources (e.g., a broadband radio such as an LTE modem).

Thus, the UE **1010** can utilize various techniques for managing coexistence between multiple radios utilized by the UE **1010**, as generally described herein.

To mitigate at least the above shortcomings, the UE **1010** can utilize features described herein and illustrated by the system **1000** to facilitate support for multi-radio coexistence within the UE **1010**. For example, a resource monitoring module **1012**, a resource separation module **1014**, and a radio access technology (RAT) scheduling module **1016** may be implemented. The resource monitoring module **1012** monitors the resources allocated to a mobile wireless services (MWS) RAT. The resource separation module **1014** monitors the separation between the MWS RAT's allocated resources and a wireless connectivity network (WCN) operating band. The RAT scheduling module **1016** may enable operation of WCN RATs and MWS RATs depending on the separation between the MWS RAT's allocated resources and the WCN operating band using the methods described below. The various modules **1012-1016** may, in some examples, be implemented as part of a coexistence manager such as the C×M **640** of FIG. **6**. The various modules **1012-1016** and others may be configured to implement the embodiments discussed herein.

FIG. **11** is a block diagram of a multi-radio wireless device **1100** according to one aspect of the disclosure. As FIG. **11** illustrates, the wireless device **600** includes a mobile wireless services (MWS) radio access technology (MWS RAT) **1120***a* and a wireless connectivity network (WCN) radio access technology (WCN RAT) **1120***b* that are coupled to antennas **1110***a* and **1110***b*, respectively. In this configuration, the MWS RAT **1120***a* may be an LTE RAT and the WCN RAT **1120***b* may be a Bluetooth (BT) or wireless local area network (WLAN) RAT that operates within the ISM band. It should be appreciated, however, that the MWS RAT **1120***a* is not limited to LTE and could be another radio access technologies, including WiMAX and other like mobile wireless service technologies. It should also be appreciated that respective RATs **1120** can be coupled to any number of antennas **1110** and that multiple RATs **1120** can also share a given antenna **1110**.

In this configuration, the multi-radio wireless device **1100** includes a coexistence interface **1130** according to, for example, a universal asynchronous receiver/transmitter (UART). Representatively, the coexistence interface **1130** is configured as a two-wire asynchronous, message based serial interface. A UART word format for communication over the coexistence interface **1130** is shown in Table 1. The message types communicated over the coexistence interface **1130** are shown in Table 2.

TABLE 1

LTE Coexistence UART Word Format

b0	b1	b2	b3	b4	b5	b6	b7
Type[0]	Type[1]	Type[2]	MSG[0]	MSG[1]	MSG[2]	MSG[3]	MSG [4]

TABLE 2

LTE Coexistence UART Message Types

Message Type	Direction	Message Type Indicator
Real Time Signaling Message	MWS <-> BT	0x00
Transport Control Message	MWS <-> BT	0x01
Transparent Data Message	MWS <-> BT	0x02
MWS Inactivity Duration Message	MWS -> BT	0x03
MWS Scan Frequency Message	MWS -> BT	0x04
RFU	MWS <- BT	0x03, 0x04
RFU		0x5
Vendor Specific		0x6-0x7

The Real Time Signaling Message is a bi-directional communication message that provides a real time status report between the MWS and WCN RATS **1120** (e.g., when the MWS RAT **1120***a* or the WCN RAT **1120***b* is transmitting or receiving, this status is communicated to the other RAT). For example, the real time status report may include instantaneous resources (e.g., time and frequency resources) that are allocated to LTE and/or to ISM. The instantaneous resources may be identified by an indication of the time and frequency resources that is received by the MWS RAT **1120***a* or the WCN RAT **1120***b* at any instance in time, such as every millisecond or a time that is shorter or longer than a millisecond. The Transport Control Message is a bi-directional messages that enables the request of a Real Time Signaling Message. For example, when the MWS RAT **1120***a* awakes from a sleep state, a Transport Control Message may be issued to determine a real time status of the WCN RAT **1120***b*. Transparent Data Messages contain data payload and are generated by higher-layer protocols.

As further illustrated in Table 2, the MWS Inactivity Duration Message is a unidirectional message from the MWS RAT **1120***a* to the WCN RAT **1120***b* that provides a sleep indication duration. The MWS Scan Frequency Message is a unidirectional message from MWS RAT **1120***a* to the WCN RAT **1120***b* to notify the WCN RAT **1120***b* that the MWS RAT **1120***a* is performing a frequency scan.

As shown in FIG. **11**, the MWS RAT **1120***a* and the WCN RAT **1120***b* are collocated within the multi-radio device **1100**. Consequently, collocated interference **1102** is experienced when the MWS RAT **1120***a* and the WCN RAT **1120***b* operate on adjacent bands. For example, the MWS RAT **1120***a* may be an LTE modem and the WCN RAT **1120***b* may be a BT or WLAN modem that operates within the ISM band. As noted in FIG. **9**, WCN (e.g., BT and WLAN) and MWS (e.g., an LTE modem) radio access technologies operate on adjacent bands, resulting in the collocated interference **1102** shown in FIG. **11**.

As explained in FIG. **9** and shown in FIG. **11**, interference may occur when the WCN RAT **1120***b* (e.g., an Industrial, Scientific, and Medical (ISM) radio) receives at the same time the MWS RAT **1120***a* in the device using a proximate frequency bandwidth (e.g., a Long Term Evolution (LTE) radio) transmits. Similarly, interference may occur when the MWS RAT **1120***a* receives and the WCN RAT **1120***b* transmits. To reduce the interference and manage inter-radio coexistence, it is desirable to coordinate behavior of the radios to reduce the time one radio is receiving while another, potentially interfering, radio is transmitting. One aspect of the present disclosure uses information about dynamic resource allocation in the MWS RAT to improve MWS and WCN radio access technology coexistence.

One feature of LTE communications that may be exploited for purposes of coexistence management is the timing of scheduling of LTE communications. Downlink (DL) communications from a base station to a user equipment (e.g., multi-radio wireless device **1100**) are scheduled via a downlink indication that tells the user equipment (UE) that the base station is sending data intended for that UE. Such allocations may be broadcast to UEs served by the particular base station every 1 ms. In a downlink allocation (also called a downlink grant) a base station will indicate to the UE the specific resource blocks that contain the data intended for the UE.

Resource blocks (RBs) are specific units of time and frequency that may be used for communications. For example, FIG. **12** is a diagram **1200** that shows downlink control information (to the left of the illustration) included in certain resource blocks of the subframe. Contained in that control information is a downlink grant indicating to the UE where in the subframe the UE may find the downlink resources that carry the downlink data destined for the UE. For downlink allocations, a base station typically notifies a UE of intended data sent during the same subframe as the downlink allocation. For example, a downlink allocation sent to a UE during subframe **0** typically indicates that there is data intended for the UE in specific resource blocks in subframe **0**. The 1 ms time frame may correspond to the instance in time that the indication of the time and frequency resources are communicated between the MWS RAT **1120***a* and the WCN RAT **1120***b*.

Uplink (UL) communications from a user equipment (UE) to a network base station in LTE are similarly scheduled by the network. That is, a base station may send a message (uplink grant) to a UE indicating to the UE when the UE is scheduled to transmit to the base station and what specific resource blocks the UE is to use. Uplink grants are typically sent on the Physical Downlink Control Channel (PDCCH).

Unlike downlink grants, however, uplink grants may be sent in advance of the subframes in which the UE is to perform uplink communications. To allow sufficient time for an uplink grant to be received by the UE in advance of the scheduled uplink time, an uplink grant may be sent in advance of the scheduled uplink time. Specifically, in LTE the uplink grant may be sent to the UE during a downlink communication that is at least 4 subframes (i.e., 4 ms) ahead of when the uplink communication is to occur. For example, an uplink grant sent during subframe **0** may indicate that the UE should transmit on certain resource blocks during subframe 4. FIG. **13** is a timing diagram **1300** that shows the an uplink grant message sent from the base station to the UE during the downlink control portion of subframe n. That uplink grant message indicates to the receiving UE that the UE should transmit uplink data to the base station during subframe n+4.

In frequency division duplexed (FDD) LTE communications, if an uplink grant is sent at subframe n, the time between the sending of the uplink grant and the scheduled uplink time is n+4 ms. In time division duplexed (TDD) LTE communications, if an uplink grant is sent at subframe n, the time between the sending of the uplink grant and the scheduled uplink time is n+k where k may vary from 4 to 7 ms. Thus, assuming that a UE can decode and parse an uplink grant within approximately 0.5 ms, the UE will have between 3.5 ms and 6.5 ms between when it knows it will be transmitting using an LTE radio and when the LTE radio actually transmits.

Advance knowledge of LTE communication activity may allow a UE, and in particular a coexistence manager, to coordinate activity between an LTE radio and ISM radio to reduce interference. Specifically, the downlink grants and uplink grants identify to the UE the specific time and resource blocks to be used by an LTE radio for uplink and downlink communications. Other information, such as expected LTE transmit power, may also be considered by a coexistence manager to determine whether interference between LTE activity and ISM activity is likely, and if so, how to adjust ISM activity to mitigate potential effects of such interference.

For example, if communication resources to be used by a LTE radio are sufficiently removed from resources to be used by an ISM radio, a coexistence manager may not alter scheduled ISM communication activity. If, however, the communication resources used by the radios are sufficiently close together, the coexistence manager may halt or alter planned ISM communication activity to prevent interference. For example, as shown in the block diagram **1400** of FIG. **14**, the LTE resources **1402** are far enough away from an ISM communication band (also called a WCN operating band) **1410**. As a result, a coexistence manager may not alter ISM communication activity. The LTE resources **1404**, however, are close to the ISM communication band **1410**. Due to the potential interference, the coexistence manager may alter ISM communication activity.

FIG. **15** provides a block diagram **1500** that shows another example of LTE communication resources that may result in altered ISM communication activity. Specifically, a coexistence manager may restrict ISM transmission (Tx) activity during a time period and frequency of expected LTE downlink control information.

It should be noted that determination of potential interference depends on the direction of planned LTE and ISM communications. When both radios are receiving, interference is not likely. Similarly, when both radios are transmitting, interference is not likely. If, however, one radio is transmitting, receiving activity by the other may be interfered with.

For potentially interfering communications, the coexistence manager may also consider the planned transmission power of the transmitting radio. If the transmission power is low, interference may be less likely. If the transmission power is high, interference may be more likely. In one aspect the coexistence manager may consider transmission power in the context of the distance between communication resource blocks to be used by the individual radios. For example, if an LTE radio is performing uplink communications using a high transmit power, the coexistence manager may halt or reschedule ISM downlink communications within a larger range of frequency than if the LTE radio were performing uplink communications using a low transmit power. Similarly, if an ISM radio is scheduled to perform uplink communications with a high power, the coexistence manager may halt or reschedule those ISM uplink communications if an LTE downlink grant indicates the LTE radio will be using resource blocks close to the ISM radio. The coexistence manager may be less likely to halt or reschedule those ISM uplink communications if the ISM radio were scheduled to transmit at a lower power or if the LTE radio was scheduled to use resource blocks farther away from those used by the ISM radio. FIG. **16** is a graph **1600** that illustrates this relationship between transmission power and resource block separation in determining an allowable region for operation of ISM communications.

In addition to halting or rescheduling ISM communications, a coexistence manager may reconfigure ISM communications based on planned LTE activity. For example, if a WiFi radio knows that an LTE radio is about to commence transmission, the WiFi radio may withhold a planned transition from 5 GHz operation to 2 GHz operation, as the 2 GHz operation is more likely to collide with the LTE uplink. Instead the WiFi radio may continue to operate in a 5 GHz band until the potential interference has passed. Thus, the WiFi radio may improve its performance by avoiding activity that is likely to be interfered with by the LTE uplink.

FIG. **17** is a block diagram illustrating method **1700** for using dynamic resource allocation information in an MWS RAT to improve MWS and WCN radio access technology coexistence according to one aspect of the present disclosure. As shown in FIG. **17** a UE may receive an indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT), as shown in block **1702**. A UE may schedule communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity, as shown in block **1704**.

FIG. **18** is a diagram illustrating an example of a hardware implementation for an apparatus **1800** employing a wireless communication system **1814**. The wireless communication system **1814** may be implemented with a bus architecture, represented generally by a bus **1824**. The bus **1824** may include any number of interconnecting buses and bridges depending on the specific application of the wireless communication system **1814** and the overall design constraints. The bus **1824** links together various circuits including one or more processors and/or hardware modules, represented by a processor **1826**, a receiving module **1802**, a scheduling module **1804**, and a computer-readable medium **1828**. The bus **1824** may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further.

The apparatus includes the wireless communication system **1814** coupled to a transceiver **1822**. The transceiver **1822** is coupled to one or more antennas **1820**. The transceiver **1822** provides a means for communicating with various other apparatus over a transmission medium. The wireless communication system **1814** includes the processor **1826** coupled to the computer-readable medium **1828**. The processor **1826** is responsible for general processing, including the execution of software stored on the computer-readable medium **1828**. The software, when executed by the processor **1826**, causes the wireless communication system **1814** to perform the various functions described supra for any particular apparatus. The computer-readable medium **1828** may also be used for storing data that is manipulated by the processor **1826** when executing software. The wireless communication system **1814** further includes the receiving module **1802** for receiving an indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT) and the scheduling module **1804** for scheduling communications of a wireless connectivity network (WCN) RAT based at least in part on the indication of the time and frequency resources of the future activity. The receiving module **1802** and the scheduling module **1804** may be software modules running in the processor **1826**, resident/stored in the computer readable medium **1828**, one or more hardware modules coupled to the processor **1826**, or some combination thereof. The wireless communication system **1814** may be a component of the UE **250** and may include the memory **272** and/or the processor **270**.

In one configuration, the apparatus **1800** for wireless communication includes means for receiving The means may be the receiving module **1802** and/or the wireless communication system **1814** of the apparatus **1800** configured to perform the functions recited by the means. The means may include the receiving module **1802**, processor **270/1826**, memory **272**, computer-readable medium **1828**, receiver **254**, transceiver **1822**, antennae **252/1110/1820**, resource monitoring module **1012**, resource separation module **1014**, coexistence manager **640** and/or coexistence interface **1130**. In another aspect, the aforementioned means may be any module or any apparatus configured to perform the functions recited by the aforementioned means.

In one configuration, the apparatus **1800** for wireless communication includes means for scheduling. The means may be the scheduling module **1804** and/or the wireless communication system **1814** of the apparatus **1800** configured to perform the functions recited by the means. The means may include the scheduling module **1804**, processor **270/1826**, memory **272**, computer-readable medium **1828**, RAT scheduling module **1016**, coexistence manager **640** and/or coexistence interface **1130**. In another aspect, the aforementioned means may be any module or any apparatus configured to perform the functions recited by the aforementioned means.

The examples above describe aspects implemented in an LTE system. However, the scope of the disclosure is not so limited. Various aspects may be adapted for use with other communication systems, such as those that employ any of a variety of communication protocols including, but not limited to, CDMA systems, TDMA systems, FDMA systems, and OFDMA systems.

It is understood that the specific order or hierarchy of steps in the processes disclosed is an example of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged while remaining within the scope of the present disclosure. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The steps of a method or algorithm described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

The previous description of the disclosed aspects is provided to enable any person skilled in the art to make or use the present disclosure. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects without departing from the spirit or scope of the disclosure. Thus, the present disclosure is not intended to be limited to the aspects shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. A method of wireless communication, comprising:

receiving a downlink or an uplink indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT), in which the downlink indication is in a same subframe as the time and frequency resources or the uplink indication is in a different subframe from the time and frequency resources; and

scheduling communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity including a frequency separation between resources to be used by the MWS RAT and resources to be used by the WCN RAT.

2. The method of claim **1**, in which the scheduling communications of the WCN RAT is further based at least in part on a scheduled transmission power for a transmission of the MWS RAT or the WCN RAT.

3. The method of claim **1**, in which the scheduling communications of the WCN RAT comprises changing a planned WCN communication mode.

4. The method of claim **1**, further comprising cancelling a planned downlink reception of the WCN RAT during a scheduled time for uplink communication of the MWS RAT.

5. An apparatus for wireless communication, comprising:

means for receiving a downlink or an uplink indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT), in which the downlink indication is in a same subframe as the time and frequency resources or the uplink indication is in a different subframe from the time and frequency resources; and

means for scheduling communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity including a frequency separation between resources to be used by the MWS RAT and resources to be used by the WCN RAT.

6. The apparatus of claim **5**, in which the means for scheduling communications of the WCN RAT is further based at least in part on a scheduled transmission power for a transmission of the MWS RAT or the WCN RAT.

7. The apparatus of claim **5**, in which the means for scheduling communications of the WCN RAT comprises means for changing a planned WCN communication mode.

8. The apparatus of claim **5**, further comprising means for cancelling a planned downlink reception of the WCN RAT during a scheduled time for uplink communication of the MWS RAT.

9. A computer program product, comprising:

a computer-readable medium having program code recorded thereon, the program code comprising:

program code to receive a downlink or an uplink indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT), in which the downlink indication is in a same subframe as the time and frequency resources or the uplink indication is in a different subframe from the time and frequency resources; and

program code to schedule communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity including a frequency separation between resources to be used by the MWS RAT and resources to be used by the WCN RAT.

10. The computer program product of claim **9**, in which the program code to schedule communications of the WCN RAT is further based at least in part on a scheduled transmission power for a transmission of the MWS RAT or the WCN RAT.

11. The computer program product of claim **9**, in which the program code to schedule communications of the WCN RAT comprises program code to change a planned WCN communication mode.

12. The computer program product of claim **9**, in which the program code further comprises program code to cancel a planned downlink reception of the WCN RAT during a scheduled time for uplink communication of the MWS RAT.

13. An apparatus configured for wireless communication, the apparatus comprising:

at least one processor; and

a memory coupled to the at least one processor, wherein the at least one processor is configured:

to receive a downlink or an uplink indication of time and frequency resources of future activity of a mobile wireless service (MWS) radio access technology (RAT), in which the downlink indication is in a same subframe as the time and frequency resources or the uplink indication is in a different subframe from the time and frequency resources; and

to schedule communications of a wireless connectivity network (WCN) radio access technology (RAT) based at least in part on the indication of the time and frequency resources of the future activity including a frequency separation between resources to be used by the MWS RAT and resources to be used by the WCN RAT.

14. The apparatus of claim **13**, in which the at least one processor configured to schedule communications of the WCN RAT is further based at least in part on a scheduled transmission power for a transmission of the MWS RAT or the WCN RAT.

15. The apparatus of claim **13**, in which the at least one processor configured to schedule communications of the WCN RAT comprises program code to change a planned WCN communication mode.

16. The apparatus of claim **13**, in which the at least one processor is further configured to cancel a planned downlink reception of the WCN RAT during a scheduled time for uplink communication of the MWS RAT.

* * * * *